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LIMNOLOGICAL AND FISHERY ASSESSMENT OF 23 ALASKA PENINSULA AND ALEUTIAN AREA LAKES, 1993-1995: AN EVALUATION OF POTENTIAL SOCKEYE AND COHO SALMON PRODUCTION

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INTRODUCTION

Limnology is the comprehensive and integrative (physics, chemistry, and biology) study of inland waters. Understanding aquatic ecosystems is important for both the conservation and appropriate use of lake and riverine habitat for commercial, sport, and personal use fisheries throughout the world. In the Pacific northwest, lakes and their tributaries are important spawning habitat and nurseries for juvenile salmonids, particularly that of sockeye salmon *Oncorynchus nerka*. It has long been recognized that growth and production of young sockeye salmon are strongly influenced by their freshwater rearing conditions (e.g., Foerster 1944: Krohkin 1967). There is compelling evidence that this freshwater life history stage is a major determinant of sockeye salmon abundance and thus is a key element in the production of adult salmon (Ricker 1937; Barnaby 1944; Foerster 1968; Hyatt and Stockner 1987; Koenings et al. 1987; Plante and Downing 1993; Luecke et al. 1995).

In Alaska, there has been considerable limnological work in many different geographical coastal regions from the southeast panhandle, to Prince William Sound and the Kenai Peninsula, and westward to the Kodiak Archipelago and the Alaska Peninsula. Concerning the latter, Atwood (1911) a government geologist surveying the area suggested that despite the volcanic nature of the region, the morphometry (depth and shape) of several large Alaska Peninsula lakes including Becharof, Ugashik, Naknek, and Kukaklek was due to glaciation. As to regional nutrients status, inorganic nitrogen concentrations were found to vary directly with the slope of the watershed, whereas phosphorus was inversely related to watershed slope in several lakes on Afognak Island (Dugdale and Dugdale 1961). For these lakes, there appeared to be a nutrient gradient which coincided with primary productivity. Although, geomorphology and drainage basin characteristics are fundamental to understanding a lake's limnology, most of the limnological interest in the Kodiak-Alaska peninsula region has dealt with freshwater conditions in relation to sockeye salmon production.

Many of the limnology and fishery related studies in this region focused on the factors responsible for the wide fluctuations in sockeye salmon abundance. Karluk Lake on Kodiak Island was the site of some of the earliest limnological research as related to sockeye salmon production (Gilbert and Rich 1927; Juday et al. 1932). These studies indicated that nutrients (phosphorus) and food supply (zooplankton) may limit juvenile production. Subsequent studies of the Karluk Lake sockeye salmon run focused on both freshwater and marine related factors responsible for its decline and suggested various management strategies for its restoration (Barnaby 1944; Rounsefell 1958; Van Cleve and Bevan 1973; Koenings et al. 1987). Nearly forty years ago, Bare Lake on Kodiak Island was the first lake in Alaska to be manipulated via supplemental nutrient additions (Nelson and Edmondson 1955). Bare Lake was artificially fertilized to determine whether increasing nutrient levels could increase freshwater growth and survival of juvenile sockeye salmon and increase their survival to adult stage. As a result of these nutrient additions, photosynthesis increased, plankton were more abundant, and larger sized smolt emigrated from the lake. Narver (1966) also stressed the importance of nitrogen and phosphorus as well as plankton levels relative to sockeye production in the Chignik Lake drainage. The contribution of sockeye salmon carcasses to nutrient loading and its effect on higher trophic levels was also viewed as important to the cyclic nature of adult returns to Lake

Iliamna (Donaldson 1967; Mathisen 1972). The mineral content of spawned-out salmon contributed large amounts of phosphorus and nitrogen to the water column for primary production and subsequent incorporation into food resources for rearing sockeye juveniles. In addition to the importance of biogenic fertilization, Eicher and Rounsefell (1957) and Rogers (1979) suggested deposition of volcanic ash originating from a chain of active volcanoes in western Alaska increased lake fertility, resulting in greater plankton abundance and larger smolt sizes in some Alaska Peninsula and Kodiak-Afognak Island lakes. Goldman (1960) suggested that differences in primary productivity (carbon fixation rates) may underlie the variation in sockeye production in Brooks, Becharof, and Naknek Lakes. Although, the experimental work of Goldman indicated nitrogen (nitrate) deficiency in these lakes, recent limnological studies indicated that phosphorus is the primary nutrient limiting productivity in lakes of the Naknek River drainage (LePerriere 1993).

The Alaska Department of Fish and Game (ADF&G) has also been conducting limnological and fishery research on a number of lakes on both Kodiak and Afognak Islands and on the Alaska Peninsula (McNair and Holland 1993; McNair 1995 and 1996). For example, Koenings and Burkett (1987) showed that the timing of fry emergence with spring and fall plankton blooms was critical to juvenile sockeye production in Karluk Lake. The negative impacts of excessive planktivory or overgrazing by juvenile sockeye was clearly demonstrated in nearby Frazer Lake as juvenile recruitment from successive high escapements reduced zooplankton densities and decreased subsequent smolt sizes (Kyle et al. 1988). Low nutrients were thought to limit sockeye production in several Afognak Island lakes e.g., Afognak Lake (White et al. 1990), Malina Lake (Kyle and Honnold 1991), Laura Lake (Honnold and Edmundson 1993), Portage Lake (White and Edmundson 1993) and Little Waterfall Lake (Edmundson et al. 1994a). As a result, these lakes were fertilized and the limnological effects of nutrient additions have been and continue to be monitored and evaluated relative to sockeye salmon (fry and smolt) production. In most of these lakes, there has been an increase following fertilization in total phosphorus, phytoplankton (chlorophyll), and the amount of forage (zooplankton) available for rearing juvenile sockeye salmon (G.Kyle, ADF&G, personal communication, Soldotna).

Zooplankton biomass has also been used as a criteria by ADF&G for determining fry stocking rates in several lakes, most notably in Spiridon Lake (Kyle et al. 1990). In this non-anadromous or barren lake, annual fry plants have created a successful new commercial fishery on southern Kodiak Island (Nelson and Barrett 1994; Nelson and Swanton 1996). In other studies, the interaction between juvenile sockeye salmon and stickleback (not low nutrients and primary productivity) was hypothesized as a plausible mechanism for the decline in smolt production in Akalura Lake (Edmundson et al. 1994b). It has also been hypothesized that large populations of Dolly Varden might also be an important factor limiting smolt production in Akalura Lake (C. Swanton, ADF&G Kodiak, personal communication). The 1989 Exxon Valdez oil spill, which closed many of the commercial fisheries in the Kodiak area, prompted the investigation of the impact of large escapements on smolt production and subsequent adult returns to Red and Akalura Lakes (Schmidt and Tarbox 1993; Schmidt et al. 1993; Honnold 1993; Swanton et al. 1996). These investigations focused on the rearing capacity of the lakes and the availability of forage (zooplankton) to higher densities of sockeye salmon fry. On the Alaska Peninsula, recent limnological studies indicated that nutrient concentrations and plankton densities may have changed over the past 30 years in Chignik Lake (Kyle 1992). Several lakes in the vicinity of

Cold Bay were recently evaluated for potential sockeye salmon production or rearing capacity using limnological characteristics (Kyle et al. 1993). The limnology of these lakes as a group was unique in terms of sockeye salmon habitat in that some were very shallow, brackish or saline, and the zooplankton community was dominated by various marine taxa.

For most of the Alaska Peninsula and Aleutian area, however, little is known about the region's watersheds that support salmon. Several large, and many small, lake and river systems in this area produce sockeye and coho salmon *O. kisutch* which contribute to the local fisheries. Salmon fisheries in the Alaska Peninsula Management Area (Figure 1) date back to 1888 with the construction of canneries at Orzinski Bay and Thin Point Cove (Shaul et al. 1993). The earliest harvest records for the Alaska Peninsula date back to 1906, whereas commercial catches were first recorded in 1911 for the Aleutian Islands Management Area (McCullough et al. 1995). There are reportedly nearly 600 salmon systems in this region of which 70 support sockeye salmon runs and 105 have coho salmon runs (Murphy 1992). The remaining runs are comprised of pink and chum salmon. Fishers within the Alaska Peninsula area have expressed interest in resolving an array of mixed-stock (local and non-local) interception issues that are frequently the focus of salmon fisheries. In response to local interests including the Alaska Peninsula/Aleutians Islands Regional Planning Team (Area M RPT), ADF&G requested funding to conduct a comprehensive limnological and fishery survey of 23 lakes in this area to determine the potential for sockeye and coho salmon rehabilitation and enhancement. As a result of approved funding, limnological surveys were initiated in 1993 and continued over a 3 year period.

Our primary objectives were to determine the bathemetry, water chemistry, nutrient status, and plankton production of the 23 study lakes. In addition, we assessed the diet of juvenile sockeye and coho fry collected from several of the shallow lakes. Smolt size and age composition were determined for emigrant smolt from Orzinski, Sandy, Bear, and Sapsuk Lakes. We also identified stream blockages or barriers which prevented or hindered adult upstream migration and quantified potential spawning habitat within the Bear and Sapsuk Lake drainages. For those lakes in which data were available, we evaluated escapement and harvest trends. Finally, we evaluated sockeye and coho salmon stocks for migration timing, availability, and disease incidence to identify potential brood sources for fish culture. Herein, we summarize the results of the fisheries and limnological investigations of the 23 Alaska Peninsula and Aleutian area lakes, evaluate their production potential, and provide recommendations for sockeye and coho enhancement.

Description of Study Area

The study area encompassed Ilnik Lake (159° 41' W. Longitude, 56° 34' N. Latitude) on the Alaska Peninsula to Kashega Lake on Unalaska Island (167° 07' W. Longitude, 53° 27' N. Latitude) in the Aleutians (Figure 2). In order to ascertain regional fishery and limnological trends or characteristics, the lakes were grouped into four regions: Southcentral, Cold Bay, Northcentral, and Unalaska Island (Table 1).

The Southcentral region includes Orzinski, Red Cove, John Nelson, Acheredin, and Wosnesenski Lakes. These lakes drain into the Gulf of Alaska. Sockeye, coho, pink *O. gorbuscha* and chum salmon *O. keta* are produced from these systems, however, the salmon harvest in the region is predominately pink salmon. Some of the area lakes (Orzinski, Red Cove, and John Nelson) are at or near sea level and are influenced by saltwater intrusion.

The Cold Bay lakes include Mortensen, Thin Point, Morzhovoi, Charlie Hansen, and Swedes and drain into the Gulf of Alaska with salmon production contributing to the post June fisheries. Pink and chum salmon are the targeted species within this region, during July and August.

Lakes in the northcentral region are Ilnik, Wildman, Sandy, Bear, Sapsuk, Big Fish, and Southwest (Coast) which drain into the Bering Sea. Sockeye salmon runs are largest in this area followed by coho and chum salmon runs. Most sockeye salmon escapement into the different systems is complete by the end of July; however, Bear River has a second run in August, which lasts into September (Nelson and Murphy 1996; Murphy et al. 1995). Wildman Lake drains into Ilnik Lake in some years but may also drain into Ocean River. The Ocean River watershed is unstable and in the past has drained directly into the Bering Sea (1972-1975 and 1986-1987).

Lastly, the Unalaska area lakes are Summer Bay, Unalaska, McLees, Volcano, and Kashega. Unalaska Island Lakes drain into the Bering Sea and are isolated geographically from Alaska Peninsula lakes. The area has runs of sockeye, coho, pink, and chum salmon with pink salmon being the only commercially targeted species (Shaul and Berceli 1995). There is also a small subsistence fishery which operates on local salmon stocks (McCullough et al. 1995).

METHODS

Lake Sampling Protocol

During 1993-1995, a total of 146 limnological surveys were conducted on 23 Alaska Peninsula and Aleutian Island lakes (Table 1). In 1993, 14 lakes were sampled twice; either in July and August or August and September. In 1994, surveys were conducted on all 23 lakes at ~4-6 week intervals during the ice free season (May-September) for a total of four surveys per lake. In 1995, sampling was discontinued in all but 8 lakes. Thus, except for the six lakes on Unalaska Island that were sampled for one year (1994), the other lakes were sampled for multiple (2-3) years. Float-equipped aircraft provided transportation to and from sampling sites. Surveys were conducted after mooring to an anchored buoy (station) at the deepest point of the lake. Because of their relatively large areas, two sampling stations were established at Bear, Charlie Hansen, and Sapsuk Lakes. At each station we measured temperature, dissolved oxygen, light penetration, and collected both water and plankton samples. The methodologies are described in detail below for each of the limnological parameters.

Lake Morphometry and Water Residence Time

An Eagle[1] model mach 1 graph recorder (fathometer) was used to chart the bathymetry (bottom profiles) of each lake. The depth sounder (transducer) was attached to the aircraft pontoon, submerged just below the lake surface. Depth soundings were made along pre-determined transects perpendicular to the long axis (maximum length) of the lake and recorded on chart paper (echogram). Transects were surveyed at a constant speed (~1 m s^{-1}) and we assumed the time interval for each transect to be proportional to distance. Depth measurements were plotted to scale onto an enlarged map of the lake surface area. Points of equal depth were then connected by contours. Surface area (SA) of each contour was determined using a calibrated polar planimeter. Basin volume (V) was derived by summing the volume contained within each stratum bounded by depth contours (Hutchinson 1957; Wetzel and Likens 1991). The maximum depth (Z_x) is the greatest recorded depth and the mean or average depth (Z) was derived by dividing the lake volume by the surface area (V/SA). Water or hydraulic residence time (HRT) is defined as the total amount of time for the water within the lake to be replaced; HRT was estimated using multiple regression analysis of lake watershed characteristics (drainage area and mean annual precipitation) versus known stream flows within the Chugach National Forest (Anonymous 1979) as follows:

$$\text{Tw (yr)} = V/TLO$$

Where:	T_w =	theoretical water residence time (years)
	V=	total lake volume (x 10^6 m^3)
	TLO =	total lake outflow (x 10^6 m^3 / year)

Light and Temperature

Underwater light intensity (foot-candles) or downward irradiance was measured using an International Light model 1350 submersible photometer sensitive to the visible spectral range (400-700 nm). Measurements were taken at 0.5-m increments from the surface to a depth of 5 m, and at subsequent 1-m increments to the lake bottom or to a depth equivalent to 1% of the subsurface reading. The vertical extinction coefficient for downward irradiance (K_d, m^{-1}) is obtained from the relation:

$$I_z = I_o e^{-Kd} \text{ or } \ln I_z = \ln I_o - K_d z$$

where I_z and I_o are the values of light penetration at z meters (m) and just below the surface, respectively (Wetzel and Likens 1991). The linear regression coefficient of ln I_z against depth (z) gives the value of K_d. Assuming K_d is constant with depth, the euphotic zone depth (EZD) or the depth at which 1% of the subsurface light remains, is given by 4.6/K_d (Kirk 1994). We also measured water transparency using a standard 20-cm diameter black and white Secchi disk as the depth at which the disk just disappears from view. Vertical profiles of temperature were taken at

[1] Mention of commercial products and trade names does not constitute endorsement by ADF&G.

1-m increments from the surface to the bottom or to a maximum depth of 50 m using a YSI model 57 or 53 analyzer. The temperature probe was calibrated periodically against a mercury thermometer at 0° C.

General Water Chemistry and Nutrients

For each survey, dissolved oxygen at the surface was measured using the Winkler method (APHA 1985) in order to calibrate the analyzer. At each lake, dissolved oxygen concentrations were measured at 1-m increments throughout the water column or to a maximum depth of 50 m using a YSI model 57 or 53 oxygen analyzer. Discrete water samples for general water chemistry and nutrient analysis were collected from the 1-m stratum using a 6-L opaque Van Dorn sampler and emptying the contents into a pre-cleaned polyethylene (poly-) carboys. For the deeper lakes, additional water samples were collected from ~75% of the maximum depth. The carboys were kept cool and dark while in the field and returned to Cold Bay or Sand Point within 6 to 8 hr for filtering and preserving. Samples for color and dissolved inorganic nutrients were filtered through a rinsed 47 mm-diameter Whatman GFF cellulose fiber filter and stored frozen in acid-washed polybottles until analysis. Unfiltered samples for the analysis of total phosphorus (TP) and Kjeldahl nitrogen (TKN) were stored frozen and unfiltered water for general water chemistry analysis stored refrigerated (4° C) in clean polybottles (Koenings et al. 1987).

In the laboratory, conductivity was measured with a YSI model-32 conductance meter and the readings standardized to 25° C. Salinity was calculated from temperature compensated conductivity measurements using a linear conversion (Wooster et al. 1969; Koenings et al. 1987). The pH was measured with an Orion 499A meter. Alkalinity (mg L^{-1} as $CaCO_3$) was determined from 100-ml samples titrated with 0.02 N H_2SO_4 to pH 4.5 using the pH meter (AHPA 1985). Calcium and magnesium were determined on the same sample from separate EDTA titrations as detailed by Golterman (1969). Total iron was determined colorimetrically after HCL digestion and reduction with hydroxylamine (Golterman 1969; Strickland and Parsons 1972). Turbidity, expressed as nephelometric turbidity units (NTU), was measured with a calibrated HF model DRT100 turbidimeter. Water color was calculated from the spectrophometric absorption of filtered water samples at 400 nm converted to equivalent platinum cobalt (Pt) units after Koenings et al. (1987). Filterable reactive phosphorus (FRP) was analyzed by the molybdate blue-ascorbic acid method (Murphy and Riley 1962) as modified by Eisenreich et al. (1975). Total phosphorus (TP) was analyzed after potassium persulfate digestion using the FRP procedure (Eisenreich et al. 1975). Samples for nitrate + nitrite (NO_3^- + NO_2^-) and ammonia (NH_4^+) were analyzed on a Technicon autoanalyzer using the cadmium reduction and phenylhypochlorite methods, respectively as outlined in Stainton et al. (1977). Analysis of total Kjeldahl nitrogen (TKN) utilized the acid block digestion and phenate methodology devised by Crowther et al. (1980). Soluble reactive silicon (SR-Si) concentrations were determined using the automated ascorbic acid reduction procedure (Stainton et al. 1977). Samples for particulate organic carbon (POC) analysis were filtered (sample volume usually 0.5 or 1.0 L) under low vacuum (15 psi) onto rinsed Whatman GFF filters. Filters were stored frozen in separate plexiglas slides until analyzed. For POC analysis, we used the wet oxidation technique with dichromate as described by Newel (1982).

Chlorophyll a

Discrete depth samples for the analysis of the algal pigment chlorophyll a (chl a) were collected as described above for the water samples. For chl a analysis, we filtered 0.5 or 1.0 L of sample water through a Whatman GFF filter under 15 psi vacuum pressure. Approximately 2 ml of $MgCO_3$ were added to the final 50 ml of sample near the end of the filtration process. Filters were stored frozen and in individual plexiglas slides until analyzed. Filters were ground in 90% buffered acetone using a mechanical tissue grinder and the slurry refrigerated in separate 15-ml glass centrifuge tubes for 4 hr to ensure maximum pigment extraction. Pigment extracts were centrifuged, decanted, and diluted to 15 ml with 90% acetone (Koenings et al. 1987). The extracts were analyzed fluorometrically with a Turner 112 fluorometer equipped with a F4T5B lamp and calibrated with purified chl a (Sigma Chemical). After the initial fluorescence reading, the extract was acidifed with 0.05 ml 0.2 N HCL and reread to correct for phaeophytin (Riemann 1978).

Zooplankton

Vertical zooplankton hauls from each site and date were collected using a 0.2-m diameter, 153 um mesh, conical net. The net was pulled manually at a constant speed (~0.5 m sec^{-1}) from just off the lake bottom or from a maximum depth of 50 m to the surface. Net contents from each tow were emptied into separate 125-ml polybottles and preserved in 10% neutralized formalin. Cladocerans and copepods were identified according to taxonomic keys in Pennak (1989) and Thorp and Covich (1991). Zooplankton were enumerated and measured in triplicate 1-ml subsamples taken with a Hansen-Stempel pipette and placed in a Sedgewick-Rafter counting chamber. Lengths of 15 animals of each species were measured to the nearest 0.01 mm and the mean body length for each taxon was calculated. Biomass was estimated from specie-specific linear regression equations between length and dry weight derived by Koenings et al. (1987).

Juvenile Sockeye and Coho Salmon Sampling

In 1994, a 30 m beach seine was used to capture nearshore sockeye and coho salmon rearing in Orzinski, John Nelson, Thin Point, Morzhovi, and Sapsuk Lakes (Appendix A). Juvenile sockeye were collected in late May (early June at Orzinski) and coho salmon in late August (mid-September at John Nelson) to assess size and stomach contents. Captured juveniles were anesthetized with tricaine methanesulfonate (MS-222), to prevent regurgitation of stomach contents, preserved individually in vials containing 10% buffered formalin, and shipped to the Soldotna Limnology laboratory for analysis. Each fish was measured for length (nearest mm) and weight (nearest 0.1 g). Each stomach was extracted, contents removed, enumerated, and identified to the nearest taxon (Koenings et al. 1987).

Sockeye Salmon Smolt Age and Size

Sockeye salmon smolts were collected and sampled for age and size during outmigrations from Orzinski (1994 and 1995), Sapsuk (1995) and Sandy Lakes (1995). Smolts were collected using a fyke net placed in the outlet stream draining each respective lake (Appendix A). Smolts were anesthetized in a tricaine methanesulfonate (MS-222) solution, measured for length (nearest 1.0 mm), weight (0.1 g), and the ponderal index (condition coefficient) was calculated (Bagenal 1978). In addition, a scale smear was taken from the preferred area (INPFC 1963) of each fish, placed on a glass slide, and ages were determined using a microfiche projector. We also summarized age and size samples collected from Bear Lake smolt from 1967-1975; 1978-1980; 1986-1989; and 1992-1995. The aforementioned procedures were employed at Bear Lake for sampling during 1993-1995 (Nelson and Murphy 1995a,b; Nelson and Murphy 1996). We presume that similar methodology was used for earlier samples, however, much of the data was tabulated without citations or reference to procedures used.

Salmon Migration Barrier Assessment

Lake outlets were measured to determine the distance between the lake and salt water at approximately high tide and observations were made of any obstructions to anadromous fish migrations. We summarize the results of previous salmon migration barrier assessment surveys conducted at the outlet streams of Red Cove, John Nelson, and Wosnesenski Lakes in September 1992 by ADF&G personnel in White et al. (1993).

Spawning Habitat Evaluation

Spawning habitat was measured and evaluated on Bear and Sapsuk Lake systems (Appendix A) in July 1995 to estimate potential use by sockeye salmon. Two transects were randomly selected in each section of the spawning tributaries and the cross-sectional area was measured. The distance between each transect on each bank was measured, thus giving rectangular dimensions. The dimensions of the two banks, as well as the two transects, were averaged. The resulting average dimension of width and length were multiplied to estimate the total area (m^2) of the spawning section. The total useable spawning habitat was determined by estimating the percentage of usable spawning habitat in each survey section, and multiplying by the estimated total area (Honnold and Edmundson 1993). Useable spawning habitat was defined as flows of approximately 0.5 m sec^{-1}, water depth of 0.3-0.5 m, gravel size of 6-150 mm with <25% by volume of the gravel $\leq$6 mm, and minimal compactness (Chambers et al. 1955; Honnold and Edmundson 1993). Shoreline (lake shoals) spawning habitat estimates were based on the following assumptions/techniques (Honnold and Edmundson 1993): 1) spawning habitat was limited to a depth of 3.1 m; 2) the 3.1 m shoreline habitat was determined by planimetry of established morphometric maps; and 3) useable shoreline habitat was delineated from aerial observations of active spawning and post spawning indicators (redds) in 1995.

Escapement Estimates, Timing, and Adult Sampling

The ADF&G currently operates six escapement enumeration weirs on the Alaska Peninsula at Orzinski, Thin Point, Nelson, Sandy, Bear, and Ilnik Rivers (Figure 2). Weirs have been operational since 1985 (Shaul et al. 1986) at Bear River and since 1989 (Shaul et al. 1990) at Nelson (Sapsuk) River ; counting towers were used in prior years. The Orzinski and Ilnik systems have been weired from 1990 and 1991, respectively, to the present. The Thin Point and Sandy River weirs have been in place since 1994. A weir was installed and operated at the outlet of Morzhovoi Lake in 1995 but is still in the experimental phase.

The methodology for estimates of sockeye salmon escapement by year at each respective system are described by Johnson and Barrett (1988); Shaul et al. (1987), McCullough (1989 a,b), McCullough (1990), Shaul et al. (1991), Shaul et al. (1992), Shaul et al. (1993), Murphy et al. (1994), McCullough et al. (1994), Murphy et al. (1995) and McCullough et al. (1995). We summarize results presented in these publications and describe escapement trends. In addition, we use these data to assess the relationship of limnological variables to escapements. Nelson and Murphy (1996) compiled harvest data to determine total late run returns and return per spawner (RPS) for late run Bear River sockeye salmon. We provide an analysis of these data. We also include a brief summary of sockeye salmon escapement timing as gleaned from ADF&G Annual Management Reports. Finally, we include the results of adult sockeye sampling for age at Orzinski, Thin Point, Middle Lagoon (Morzhovoi Lake), Ilnik Lagoon, Sandy River, Bear River, and Nelson River (Sapsuk Lake). Methods used for collecting and preparation of scales are described by Nelson and Murphy (1996).

Aerial estimates (indices) of coho salmon escapement are thought to be inadequate as inclement weather causes infrequent surveys (Murphy 1995). Thus, coho salmon escapement trends are not included in this report.

Brood Source Surveys

We assessed the following parameters, as recommended by McDaniel et al. (1994), to assist in the selection of potential brood sources for sockeye salmon stocking projects: geographic proximity to the project, run timing and stock strength (escapement levels), disease history, type of spawners (inlet, outlet, shore, etc.), and migratory patterns.

In August, 1993 foot surveys of Sapsuk and Orzinski Lake tributaries were conducted to locate spawning sockeye salmon for brood stock screening. Live salmon were enumerated as surveyors walked upstream along the stream bank. Creeks were divided into 300 meter sections to minimize error in the counts due to the presence of large numbers of fish. The survey ceased once upstream observations indicated no fish present (4-5 km at Sapsuk and 1-2 km at Orzinski).

Based on the intial surveys, in 1993 female sockeye salmon from Sapsuk and Orzinski Lakes were screened for Infectious Hematopoietic Necrosis Virus (IHNV) and Bacterial Kidney Disease (BKD). John Nelson and Russell Creek coho salmon were also screened for BKD in 1993 and 1994, respectively. Salmon were captured by beach seining along the lakeshore, and ripe females were partially stripped of eggs to obtain ovarian fluid. The ovarian fluid was decanted into individual centrifuge tubes and stored on ice in a cooler. Kidney (BKD) samples were collected using a knife immersed in iodophor (betadine) solution for disinfection, and making an incision along each fish's abdomen from the vent to the ventral fins. A portion of the anterior and posterior parts of the kidney were removed and placed in a whirlpak for each fish. A total of 60 samples were obtained for both disease screenings.

RESULTS

Morphometric and Hydrological Characteristics

The morphometric characteristics of each lake are summarized in Table 2 and detailed bathymetric maps (excluding Ilnik Lake) are presented in Appendix A. Bear Lake is the deepest (Z_x, 104 m) and has the largest surface area (25.6 km^2) and volume (826.5 $m^3 \times 10^6$). The hydraulic residence time was estimated at 7.2 yr. Sapsuk Lake is nearly as deep (Z_x=87 m), but has only about half the surface area and volume compared to Bear Lake. As such, Sapsuk Lake has a slightly greater mean depth (40 m) and thus a steeper basin configuration, but a shorter water residence time (4.5 yr). Archeredin, Big Fish, Kashega, Mortensen, Morzhovoi, Southwest Coast, Thin Point, Upper Volcano, and Wosnesenski Lakes are all very shallow with mean depths of ~1 m and maximum depths of approximately 2 or 3 m. Because of their shallow morphometry, these lakes are probably fast flushing as exemplified by Morzhovoi Lake that has a rather short residence time (estimated at 0.8 yr). We were unable to develop a bathymetric map for Ilnik Lake, but it is also presumably shallow (Robert Murphy, James McCullough, ADF&G, personal communication). Depth soundings in the middle of the lake were recorded to be only 2 to 3 m. Sandy and Swede Lakes are also fairly shallow (Z=2 m). Swede Lake is small in area (3.9 km^2), but Sandy Lake has the second largest surface area (21.6 km^2) of all the study lakes. Charlie Hansen, John Nelson, McLees, Orzinski, Red Cove, Summer Bay, Unalaska, Lower Volcano, Wildman, and Wosnesenski Lakes are considered intermediate in terms of depth. As a group, the mean depth ranged from 5 to 8 m and the maximum depth from 9 to 17 m. Surface areas ranged from 0.2 km^2 (Summer Bay Lake) to 9.9 km^2 (Wildman Lake). Hydraulic residence times were estimated at 0.7 yr for Charlie Hansen Lake, 3.5 yr for Orzinski Lake, and 4.3 yr for Wildman Lake.

Light Penetration and Turbidity

The mean vertical extinction coefficient (K_d m^{-1}) or rate of light attenuation was lowest in Sapsuk Lake (0.15) and highest in Southwest Coast Lake (2.89) (Table 3). Sapsuk Lake had the greatest euphotic zone depth (EZD) (32.7 m); Southwest Coast, the lowest (1.7 m). Average Secchi disk (SD) transparency reached nearly 10 m in Sapsuk Lake, whereas in Southwest Coast Lake the SD was measured to a depth of only 0.3 m. Thus, Sapsuk Lake was the most transparent or clear and Southwest Coast Lake was the least transparent. Bear Lake was optically similar to Sapsuk Lake with a SD depth of 5.5 m, and a relatively low K_d (0.24 m^{-1}) and deep EZD (19.6 m). Other low light-attenuated or optically deep lakes included Charlie Hansen, John Nelson, McLees, Orzinski, Summer Bay, and Lower Volcano Lakes. In these lakes, K_d ranged from 0.25 to 0.37 m^{-1}, EZD from 16.9 to 13.8 m, and SD transparency from 6.3 to 3.6 m. In contrast, Big Fish, Ilnik, Mortensen, Morzhovoi, and Thin Point Lakes exhibited greater attenuation (K_d >1.0 m^{-1}), reduced transparency (SD depth 0.5-1.0 m), and therefore a shallower depth of light penetration (EZD <4 m). We considered these lakes to be highly attenuated or optically shallow. The remaining lakes (Sandy, Wildman, Wosnesenski Archeredin Upper

Volcano Kashega, Red Cove, Swede, and Unalaska) exhibited moderate light attenuation (K_d, range 0.43 to 0.69 m^{-1}) and EZD (range 11.9 to 7.0 m).

Euphotic volume (EV), the volume of water capable of net photosynthesis, was greatest in Bear and Sapsuk Lakes (Table 3). The EV comprised 46% (380 $x10^6$ m^3) of the total volume in Bear Lake and 54% (241 $x10^6$ m^3) of the total volume in Sapsuk Lake. EZD (and SD) equaled or exceeded the mean (Z) or maximum (Z_x) depth in many of the shallow lakes. That is, the entire water column was within the euphotic zone and EV was equal to the total lake volume (V). Since EV is a function of both SA and EZD, EV is largely due to SA in shallow lakes, whereas in deep lakes (e.g., Bear and Sapsuk) EZD is more important. Because of its relatively large SA, Sandy Lake had the greatest EV (53 $x10^6$ m^3) among the shallower systems. Collectively, EV for the shallow and intermediate depth lakes is 379 $x10^6$ m^3 which is equivalent to the photosynthetic capacity (i.e., EV) of Bear Lake. Although the entire water column in the shallow lakes was largely photic, K_d in several of the lakes was nonetheless considered relatively high. For example, EZD is greater than Z in Big Fish, Ilnik, Mortensen, Morzhovoi, and Thin Point Lakes; however, in these attenuation was severe (K_d >1.0 m^{-1}).

Turbidity was the most important light-attenuating component or process (Figure 3A). Considering all lakes, seasonal mean turbidity ranged from <1 to 21 NTU, whereas color was low (<15 Pt units). Morzhovoi, Big Fish, and Southwest Coast Lakes had the highest turbidity (mean 21 NTU). Turbidity was also quite high in Mortensen Lake (8.7 NTU) and Thin Point Lake (10.4 NTU). Sandy, Wildman, and Wosnesenski Lakes had substantial turbidity (mean 5 NTU). We found a strong correlation between K_d and turbidity. The linear relationship was: K_d = 0.109 + 0.282Turbidity; $r^2 = 0.93$, $P < 0.001$. In addition, lakes with the highest turbidity also had very high chlorophyll concentration. We regressed turbidity against chlorophyll concentration and derived a significant curvilinear relationship (Figure 3B): Log Turbidity = 0.076 + 0.769Log Chlorophyll; $r^2 = 0.71$; $P<0.001$. Thus, the nature of the turbidity appeared to be largely organic (i.e., phytoplankton).

Seasonal changes in turbidity (and K_d) were not always tied to varying chlorophyll concentration. For example, in Morzhovoi Lake turbidity was highest (35 NTU) in August and September 1993 when chlorophyll concentration averaged 10 ug L^{-1} (Figure 4A). However, for the same time period in 1994, chlorophyll concentration increased nearly ten-fold (98 ug L^{-1}), yet the turbidity was much lower (20 NTU). In July and August 1993, chlorophyll and turbidity levels in Thin Point Lake averaged 35 ug L^{-1} and 30 NTU, respectively. In 1994, chlorophyll levels were again much lower (3 ug L^{-1}), but turbidity was similar (25 NTU) to that in 1993. That is, although most turbid lakes had high chlorophyll levels, turbidity appeared to also have a non-algal component. Iron levels were higher in the shallow turbid lakes (mean 401 ug L^{-1}) compared to deeper clear lakes (mean 53 ug L^{-1}). In addition, seasonal changes in iron concentration tracked closely with turbidity as exemplified in Morzhovoi and Thin Point Lakes (Figure 4B). Iron like chlorophyll was highly correlated with turbidity. Thus, the high iron concentration indicated that at least in shallow lakes, turbidity is due in part to suspended inorganic material (e.g., re-suspended sediments).

Temperature and Dissolved Oxygen

For most lakes, maximum surface temperatures occurred in mid August and reached ~14-16° C (Figure 5). However, because of their large volume, maximum temperatures reached only ~10° C in both Bear and Sapsuk Lakes. On a regional scale, it appeared that spring (June) surface temperatures were ~2° C colder in the Cold Bay lakes (8-10° C) compared to those on the northern peninsula and Unalaska Island (6-8° C). There was no seasonal (May-September) development of vertical temperature gradients >1° C m^{-1} among the shallow lakes (Z <5 m); thermal stratification did not occur and these lakes circulated or mixed continuously. During the warming period (late May-early August), vertical profiles were consistent in that the surface temperatures were about the same as that at the bottom. Maximum surface temperatures (~14-15° C) in early August were 0.5 to 1° C warmer than the bottom waters. By September, the water column was isothermal within 1-3° C of the maximum temperature. A thermocline was not detectable in Bear and Sapsuk Lakes, the two deepest lakes; surface temperatures in July and August were consistently ~3° C warmer than at depth (50 m). Among the lakes of intermediate depth (Z=5-10 m), John Nelson and Red Cove Lakes were the only ones to exhibit a significant (>1° C m^{-1}) thermocline. Stratification was not readily apparent in June; however, by August a distinct thermocline had formed that extended from a depth of 7 to10 m in John Nelson Lake (Figure 6) and from 5 and 10 m in Red Cove Lake (Figure 7). A thermocline was still evident during September on the final survey of the season. In Orzinski Lake, bottom temperatures were 3° C colder than at the surface; however, a thermocline did not form. The other intermediate depth lakes were near isothermal (i.e., temperatures at the surface were nearly the same as that on the bottom).

Among the non-stratified lakes, dissolved oxygen concentrations in the spring (May-June) ranged between 12 and 14 mg L^{-1} throughout the entire water column (Table 4). During summer (July-August), dissolved oxygen levels decreased to ~9-11 mg L^{-1} near the surface and to ~7-10 mg L^{-1} near the bottom. Although the warmer water contained slightly less dissolved oxygen, concentrations remained at >80% saturation. Oxygen concentrations in the fall were similar to that found in the spring. In contrast, John Nelson and Red Cove Lakes, which were thermally stratified, exhibited prolonged periods of very low oxygen within the hypolimnion (Figures 6 and 7). Early in the season, oxygen levels in John Nelson Lake decreased from 14 mg L^{-1} in the surface to <2.0 mg L^{-1} near the bottom. Oxygen concentrations below the thermocline (>10 m) continued to decrease as the season progressed. By early August, John Nelson Lake was largely anaerobic (<0.5 mg L^{-1}) below a depth of 10 m, and this condition lasted through September. Red Cove Lake was well oxygenated (10-14 mg L^{-1}) from the surface to a depth of 10 m; however, the hypolimnion became anaerobic. Although dissolved oxygen concentrations within the epilimnion (0-10 m) remained high (>10 mg L^{-1}), hypolimnetic (>10 m) oxygen depletion or anoxia persisted in this lake throughout the entire season.

Major Dissolved Constituents

Most of the lakes had low to moderate electrolyte content as measured by conductivity (mean 115 umhos cm^{-1}). Conductivity did not change or changed very little with depth in the well mixed lakes (Table 5). In contrast, a prominent feature of John Nelson, Orzinski, and Red Cove

Lakes was the very high concentrations of dissolved solids. Conductivity in the near-surface (1-m) waters averaged 1,460 umhos cm^{-1} in Orzinski Lake, 4,890 umhos cm^{-1} in Red Cove Lake, and more than 25,000 umhos cm^{-1} in John Nelson Lake. The bottom (10-m) samples in these three lakes had a much higher conductivity than the surface and averaged 4,726, 29,351, and 47,125 umhos cm^{-1}, respectively. Large seasonal fluctuations in conductivity were not apparent for John Nelson and Red Cove Lakes, particularly near the bottom. However, conductivity of the surface samples gradually decreased from ~5,000 to 500 umhos cm^{-1} as the season progressed in Orzinski Lake.

Salinity, based on conductivity, ranged between 1 and 2 parts per thousand ($^{o}/_{oo}$) in Orzinski Lake (Table 5). As expected, salinity was much higher in both Red Cove and John Nelson Lakes and was very similar to seawater. Salinity averaged 22 $^{o}/_{oo}$ near the bottom of Red Cove Lake and ranged from 20 $^{o}/_{oo}$ in the surface to 36 $^{o}/_{oo}$ in the deeper samples of John Nelson Lake. In comparison, seawater has an average salinity of 35 $^{o}/_{oo}$. In the freshwater lakes, calcium and magnesium, two of the most important cations in lakes, averaged 7.2 and 2.3 mg L^{-1}, respectively. Concentrations increased with conductivity (salinity) and averaged 412 and 1,294 mg L^{-1} in John Nelson Lake which was equivalent to the average concentration of these cations in seawater. The calcium:magnesium ratio (by weight) averaged ~1.9 for the freshwater lakes, but as in seawater this ratio was reduced to ~0.2 in the Orzinski, Red Cove, and John Nelson Lakes. Thus, magnesium was more important (abundant) relative to calcium in the brackish-saline lakes. The hydrogen ion concentration (pH) ranged from a high of 8.4 units in Wildman Lake to 6.4 units in Sandy Lake. For most lakes, the pH was circumneutral (6.5-7.5 units). Alkalinity averaged 19 mg L^{-1} in the freshwater lakes and increased to 120 and 140 mg L^{-1} in John Nelson and Red Cove Lakes. The latter concentrations are essentially the same as that for seawater. Since the apportionment of alkalinity (carbon dioxide, bicarbonate, and carbonate) is pH dependent, the pH range exhibited by these lakes (both freshwater and brackish-saline) tends to favor the major anion bicarbonate. Thus, in terms of major dissolved constituents, Orzinski Lake is considered brackish; Red Cove, and John Nelson Lakes are saline.

Dissolved Nutrients

Inorganic dissolved nitrogen (ammonia and nitrate + nitrite) levels in the surface waters were very low in all of the lakes. Mean seasonal ammonia concentrations in the 1-m stratum ranged from <1 to 10 ug L^{-1} (Table 4). There was no detectable seasonal or any other temporal pattern for ammonia. Concentrations exhibited little vertical variation among the non-stratified lakes (Table 7). In contrast, hypolimnetic concentrations were very high in John Nelson and Red Cove Lakes and averaged 705 ug L^{-1} and 2,124 ug L^{-1}, respectively. On 21 July and 21 September 1993, ammonia levels in Red Cove Lake reached ~8,000 ug L^{-1} at a depth of 15 m. During 1994 hypolimnetic ammonia concentrations in Red Cove Lake were considerably lower (range 1,604 - 3,468 ug L^{-1}), but the samples were collected from shallower depths (10-12 m), i.e., in the upper part of the hypolimnion. For most of the lakes, nitrate + nitrite nitrogen in the surface samples was below analytical detection limit (<4 ug L^{-1}). Archeredin, Bear, John Nelson, Orzinski, and Red Cove Lakes were the only systems with appreciable levels (mean 50-200 ug L^{-1}) of nitrate nitrogen. In these lakes, nitrate levels fluctuated over the season with the highest concentration occurring in the spring and fall. Nitrate became severely depleted (<10 ug L^{-1}) in the summer, particularly in Archeredin, Red Cove, and Orzinski Lakes. Although concentrations increased slightly by the end of the season in these lakes, nitrate in Red Cove Lake remained low (~30 ug L^{-1}) into September. A summer depression in nitrate was also evident in Bear Lake, but concentrations did not fall below ~30 ug L^{-1}. There was little difference in nitrate concentration between the 1-m and deeper waters in Archeredin, Bear, and Orzinski Lakes. In contrast, although John Nelson and Red Cove Lakes had the highest nitrate levels in the surface compared to the other lakes, nitrate was low (<5 ug L^{-1}) within the hypolimnion.

Inorganic phosphorus concentration was quite variable among these lakes. Mean seasonal total filterable phosphorus (TFP) and filterable reactive phosphorus (FRP) within the 1-m stratum ranged from 2 to 124 ug L^{-1} and from <1 to 112 ug L^{-1}, respectively (Table 4). Wildman Lake had both the highest TFP and FRP concentration. Inorganic phosphorus was also very high in Ilnik, Big Fish, Mortensen, Morzhovoi, and Southwest Coast Lakes. TFP and FRP concentration in these lakes ranged from 10 to 59 ug L^{-1} and from 10 to 55 ug L^{-1}, respectively. For the remaining lakes, inorganic phosphorus concentration was relatively low with TFP ranging from 4 to 10 ug L^{-1} and FRP from 1 to 5 ug L^{-1}. Although inorganic phosphorus was low in the surface in John Nelson Lake and in Red Cove Lake, concentrations were much higher within the hypolimnion (Table 7). Below the summer thermocline, TFP and FRP averaged ~50 ug L^{-1} in John Nelson Lake and >300 ug L^{-1} in Red Cove Lake. Excluding Morzhovoi and Southwest Coast Lakes, FRP values represented from 40 to 90% (mean 70%) of TFP. In contrast, FRP comprised a much smaller proportion (mean 30%) in Morzhovoi and Southwest Coast Lakes.

Mean seasonal silica concentration in the 1-m stratum ranged from 250 to >11,000 ug L^{-1} (Table 4). Ilnik Lake had the highest silica concentration and Southwest Coast Lake had the lowest., There was no discernible temporal pattern for silica in any of the lakes, except for Wildman Lake, in which silica concentrations averaged ~4,000 ug L^{-1} in early summer, but decreased markedly to ~100 ug L^{-1} by August. Despite the lack of any definite seasonal trends in most of the lakes, the two lakes (Morzhovoi and Southwest Coast) with the lowest silica concentration (718 and 251 ug L^{-1}, respectively) also had the highest mean seasonal chlorophyll concentration (30 to 40 ug L^{-1}).

Total Phosphorus and Nitrogen

Mean seasonal total phosphorus (TP) and Kjeldahl (organic nitrogen + ammonia) nitrogen (TKN) concentrations within the 1-m stratum ranged from 3 to 226 ug L^{-1} and 52 to 1,885 ug L^{-1}, respectively (Table 6). Morzhovoi Lake had the highest TP and TKN concentration followed by Big Fish, Southwest, and Wildman Lakes. In these lakes, TP ranged between 100 and 200 ug L^{-1} and TKN from 600 to 1,500 ug L^{-1}. TP was also high in Mortensen Lake (mean 77 ug L^{-1}) and Thin Point Lake (mean 39 ug L^{-1}). In contrast, Bear Lake and Sapsuk Lake had the lowest TP (~3 ug L^{-1}) and TKN (~50 ug L^{-1}) concentrations of all the lakes. Given the near lack of nitrate and ammonia nitrogen among the 23 lakes, TN is considered to be mostly organic. In addition, much of the phosphorus is contained within the particulate phosphorus (TP - TFP) fraction among the lakes with the highest TP concentration (i.e., Mortensen, Morzhovoi, Thin Point, Big Fish, and Southwest Coast). In these lakes, TFP represented only ~10% of TP. In contrast, TFP comprised 30 to 70% of TP in the other lakes. Thus, there were large differences in the amount of inorganic and particulate phosphorus as a proportion of TP.

Mean TN:TP ratios (by weight) in the 1-m stratum ranged from a low of 6:1 in Ilnik Lake to high of 77:1 in John Nelson Lake (Table 8). The TN:TP ratio was <10:1 in Ilnik and Wildman Lakes which indicated nitrogen was limiting primary production. In contrast, TN:TP ratios exceeded 40:1 in Unalaska, Orzinski, Sapsuk, Archeredin, Bear, Red Cove, and John Nelson Lakes which implied severe phosphorus deficiency. Sandy, Thin Point, Mortensen, Upper Volcano, Morzhovoi, and McLees Lakes had TN:TP ratios considered within the optimum range (10:1 to 20:1). In the remaining lakes, the TN:TP ratio ranged between 20:1 and 40:1 which is characteristic of moderate phosphorus deficiency.

Chlorophyll a

The mean near-surface (1-m) chlorophyll a concentration range for the 23 lakes differed by nearly 100-fold, from a low of 0.49 in Kashega Lake to a high of 40.98 ug L^{-1} in Morzhovoi Lake (Table 6). Individual values fluctuated considerably over the growing season (Figure 8). In most of the lakes, maximum chlorophyll concentrations occurred in late summer or fall. Notable exceptions were Mortensen and Thin Point Lakes in which the chlorophyll maxima occurred in mid-July (at least in 1994). In addition to the seasonal variation, chlorophyll levels varied with depth in a number of lakes (Table 7). For example, in Wildman Lake summer chlorophyll levels exceeded 40 ug L^{-1} in the 1-m stratum and reached nearly 80 ug L^{-1} at the 12-m depth. Concentrations within the 10-15 m strata (mean 3. 7 ug L^{-1}) were twice as high compared to the surface (mean 1.7 ug L^{-1}) in brackish Orzinski Lake. Although there was little vertical variation among the other well-mixed lakes, concentrations changed abruptly with depth in the stratified lakes. Hypolimnetic chlorophyll levels were five-fold higher in both John Nelson and Red Cove Lakes compared to the surface.

We found a significant ($P<0.001$) relationship between TP and chlorophyll concentration (Figure 9). Following log transformation of the values for the 1-m stratum, the regression model for all lakes explained nearly 90% of the variation in chlorophyll concentration. However, chlorophyll per unit phosphorus concentration (non-transformed) was much lower in Ilnik (0.05) and Sandy (0.08) Lakes compared to the other lakes (mean 0.18). In these two lakes chlorophyll concentration was less than expected given the relatively high level of TP. Based on seasonal mean TP and chlorophyll concentration, the 23 lakes spanned the entire trophic gradient from oligotrophic (nutrient poor) to eutrophic (nutrient rich). One-third (8) of the lakes were considered oligotrophic (TP <10 ug L^{-1}; chlorophyll <1.5 ug L^{-1}), one-third (8) were mesotrophic (TP 10-20 ug L^{-1}; chlorophyll 1.5-3.0 ug L^{-1}), and one-third (7) were eutrophic (TP >20 ug L^{-1}; chlorophyll >3.0 ug L^{-1}).

Zooplankton Abundance and Species Composition

Mean zooplankton density, biomass, and body size (length) by taxa for all lake-years are presented in Appendix B. For sample years 1993-1995, the mean total macrozooplankton (TMZ) density (animals m^{-2}) ranged from a low of 51 to a high of 2.68 million, and TMZ biomass (mg m^{-2}) ranged from <1 to 3,578. Archeredin Lake (1993) had the lowest mean density and smallest biomass, whereas Wildman Lake (1993) had the highest density and greatest biomass. However, not all lakes were sampled in 1993 (n = 17) nor in 1995 (n = 8). In addition, lakes were surveyed on only ~2 occasions (July and August) in 1993 usually during peak plankton production. Therefore, the average density, biomass, and species composition derived for 1993 may not be representative of the season (May-September). As such, monthly samples collected in 1994 (4 surveys for each of the 23 lakes) provided the best data for inter-lake comparisons and seasonality of zooplankton density, biomass, and species composition.

Of all the 23 lakes sampled in 1994, Wildman Lake had the most abundant zooplankton with a average TMZ density of 1.42 million. (Table 9). The cladocerans *Daphnia* and the smaller sized *Bosmina* together comprised ~75% of the TMZ density in Wildman Lake. TMZ densities were also quite high in Bear and Sapsuk Lakes, averaging 669,321 and 522,584, respectively. Although similar in density, the species composition in these two lakes were quite different. In Bear Lake, *Bosmina* and the larger-sized cyclopoid copepod *Cyclops*, accounted for 60% and 40% of the TMZ density, respectively. In contrast, zooplankton populations in Sapsuk Lake were dominated by *Cyclops* (68%), whereas *Bosmina* represented only 38% of the density. The zooplankton density in McLees Lake was also quite abundant (165,639) and was dominated by *Bosmina* (83%). Densities in Southwest Coast (83,452) and Morzhovoi (59,218), Charlie Hansen (46,039) and Summer Bay (27,422) Lakes were considered moderate. Zooplankton were not particularly abundant in Mortensen, Lower Volcano, and Sandy Lakes. In these lakes the mean TMZ density ranged from 15,547 to 7,163. Of particular distinction is the paucity of zooplankton in a number of the freshwater lakes. For example, mean TMZ densities in Big Fish, Wosnesenski, Swede, Archeredin, Ilnik, and Unalaska Lakes ranged from 6,402 to 1,506 which were extremely low. Zooplankton were nearly absent from Thin Point, Kashega, and Upper Volcano Lakes as the TMZ densities averaged <500. Both *Bosmina* and *Cyclops* were well represented in most of the aforementioned lakes. However, *Eurytemora*, a calanoid copepod which tolerates a wide range in salinity (euryhaline) and is often associated with marine and coastal waters, was fairly ubiquitous and was the dominant (>50%) taxon in Morzhovoi, Summer Bay, Mortensen, Sandy, and Unalaska Lakes. Eurytemora was also present in Wosnesenski, Archeredin, Ilnik, and Kashega Lakes.

The zooplankton species composition among the 3 brackish-saline lakes was very different from that of the freshwater lakes. The genera *Acartia*, another important marine calanoid copepod, as well as *Eurytemora*, were common in John Nelson, Red Cove, and Orzinski Lakes (Table 9). In addition, the genera *Evadne* and *Podon*, two cladocerans associated with coastal or brackish waters, were also present in John Nelson and Red Cove Lakes. Of these lakes, John Nelson Lake had the highest mean zooplankton density (245,294) with *Acartia* and *Evadne* each representing about half of the TMZ density. Orzinski and Red Cove Lakes had comparable zooplankton densities (mean ~60,000); however, *Eurytemora* was the dominant (99%) zooplankter in Orzinski Lake, whereas *Acartia* comprised nearly all (98%) of the zooplankton in Red Cove Lake.

Seasonality in Zooplankton Abundance

Zooplankton abundance (both total and by taxon) varied markedly from month to month. For example, a distinctive feature of the zooplankton community in Bear Lake was the seasonal alternation of *Bosmina* and *Cyclops* abundance (Figure 9). *Bosmina* populations were least abundant in the spring and most abundant in late summer and fall (August-September), whereas *Cyclops* populations peaked during the spring and declined over the summer. In contrast, Wildman and Sapsuk Lakes exhibited a regular pattern of zooplankton abundance and species composition; large numbers of the dominant species occurred in the early summer (June-July), densities dropped somewhat in late summer (July-August), and then populations increased again in the fall (September). Among the other freshwater lakes, *Bosmina* density typically peaked between late August and early September (Table 10). Other cladocerans such as *Daphnia* and *Chydorinae*, although represented in only 4 of the lakes, were most abundant in September. Among the copepods, maximum *Cyclops* densities also occurred during the latter summer period; however in McLees, Southwest Coast, and Sandy Lakes *Cyclops* populations were most abundant in the spring (June). *Eurytemora* peak abundance occurred sporadically over the season from early June (e.g., Sandy Lake) to late September (e.g., Kashega Lake). Among the saline-brackish lakes, the marine copepod *Acartia* reached maximum density in July in Red Cove Lake. In contrast, *Acartia* populations were most abundant during September in John Nelson Lake. Thus, the seasonal pattern of zooplankton species abundance was not the same from lake to lake nor within a lake.

Zooplankton Biomass

Of the 20 freshwater lakes sampled in 1994, Wildman Lake had the greatest biomass followed by Bear and Sapsuk Lakes (Table 11). Mean seasonal TMZ biomass (areal) equaled 2,629, 1,847, and 944 mg m^{-2}, respectively. The within-lake biomass composition was nearly the same as that for the TMZ density. *Daphnia* which exhibited a mean body length of 0.73 mm, was responsible for most (68%) of the zooplankton standing crop in Wildman Lake. Small sized (mean 0.49 mm) *Bosmina* and the larger (0.98 mm) *Cyclops* accounted for equal proportions of the zooplankton standing crop in Bear Lake. *Cyclops* body lengths were smaller (mean 0.73 mm) in Sapsuk Lake compared to Bear Lake, but comprised two-thirds (67%) of the zooplankton biomass. However, for a number of the other lakes, total zooplankton biomass by rank did not always correspond to that based on density. For example, mean TMZ biomass was nearly the same (~150 mg m^{-2}) in McLees, Southwest Coast, and Morzhovoi Lakes, yet McLees Lake had twice the density compared with the other two lakes. This is because McLees Lake was dominated numerically (83%) by very small sized (mean 0.31 mm) *Bosmina*, whereas in Southwest and Morzhovoi Lakes zooplankton populations were comprised of the larger sized *Cyclops* (mean 0.70 mm) and *Eurytemora* (mean 0.90 mm). Similarly, Charlie Hansen Lake had twice the density of zooplankton, but less than half the TMZ biomass (40 mg m^{-2}) as that for Summer Bay Lake (95 mg m^{-2}). Small (mean 0.31 mm) *Bosmina* comprised >90% of the TMZ density in Charlie Hansen Lake and the much larger (mean 0.75 mm) *Eurytemora* represented 93% of the zooplankton density in Summer Bay Lake. Thus, between-lake comparisons of zooplankton may indicate more similarity in abundance when only density is considered, but the biomass estimate or standing crop may indicate significant differences in zooplankton among lakes. Zooplankton biomass was low (range 3-15 mg m^{-2}) in Unalaska, Ilnik, Archeredin, Swede, Wosnesenski, Big Fish, and Sandy Lakes. Thin Point, Kashega, and Upper Volcano Lakes had the lowest biomass (mean <1 mg m^{-2}) throughout the season compared to all the other lakes. Thus, nearly half (n=10) of the lakes surveyed had very low (<20 mg m^{-2}) zooplankton biomass.

Size Characteristics of Juvenile Sockeye and Coho Salmon

The mean size of juvenile sockeye salmon was assessed at Orzinski, John Nelson, Thin Point, Morzhovoi, and Sapsuk Lakes in 1994 (Table 12; Appendix C). Likewise, average juvenile coho salmon size was determined at these lakes, excluding Sapsuk. Sockeye salmon fry captured from John Nelson Lake were the largest (0.39 g; 35.4 mm). Sapsuk Lake sockeye fry were slightly smaller (0.23 g and 32.2 mm) and Thin Point and Morzhovoi Lake fry were of similar size at 0.2 g and 30 mm. Orzinski Lake juvenile sockeye were much larger (87 g and 94 mm) and were likely age 1. fish, rather than the presumed young-of-the-year fry (age 0.) sampled at the other lakes. However, none of the juvenile fish were analyzed for age ,so this presumption cannot be substantiated. Coho salmon juveniles collected at Thin Point Lake were quite large, with a weight and length of 11.9 g and 97.1 mm, respectively. John Nelson and Morzhovoi Lake coho fry were about one-third smaller (~ 4.0 g and 66 mm). Again, these fish were not differentiated by age class.

Juvenile Salmon Stomach Contents

In conjunction with size assessment, stomach content analysis was conducted on sockeye and coho salmon juveniles from John Nelson, Thin Point, Morzhovoi, and Sapsuk Lakes (Table 13; Appendix C). Only sockeye fry were sampled from Orzinski Lake.

Orzinski Lake sockeye fry stomachs (n=25) contained 180 prey items comprised of five taxa (Table 13). *Nematoda* was identified in 12 stomachs and represented 113 of the total prey items. *Gammaridae* and *Corophiidae* were also present in stomach contents.

Stomachs (n=30) from John Nelson Lake sockeye fry contained the largest number of prey items (1,888) and taxa (21). Of the total prey items examined, 1,143 were Tisbe and were found in 14 stomachs. *Harpaticus* was identified in more fish (16) but in fewer numbers (50). *Gammaridae* was also found in 13 stomachs. Coho fry stomachs sampled (n=18) revealed the same number of taxa (21), but much fewer overall prey (392). *Gammaridae* was identified in 11 of the coho fry stomachs, and *Amphipoda* found in seven.

In contrast, Thin Point Lake sockeye fry (n=25) had the fewest prey items (42) while coho fry stomachs (n=24) contained the most (747). Of the 11 taxa identified in sockeye stomachs, *Harpaticoida*, *Neomysis*, *Collembola* and *Diptera* larvae were found in four each. Although, nine taxa were found in coho stomachs, two species were dominant, *Nematoda* and *Neomysis mercedes* which were identified in 14 and 17 fish, respectively. *Nematoda* comprised 60% (444) of all prey items and *Neomysis mercedis* 38% (286).

Approximately one-third (8/25) of the stomachs examined from Morzhovoi Lake sockeye fry contained 60% (361 *Eurytemoridae*) of the prey items. The remaining stomachs (18/25) contained *Harpaticoida* in low abundance (125). Also, 13 stomachs contained *Diptera* larvae, again, in low numbers (20). All 16 coho salmon stomachs contained *Chironomidae* which comprised 64% of the total combined prey items (529). Approximately 137 *Diptera* larvae were identified in six coho stomachs.

Finally, of the 20 stomachs examined from Sapsuk Lake sockeye fry, 11 contained *Cyclops*, and *Bosmina*, and 10 contained *Cyclop* nauplii. Overall (all stomachs), the number of these species was low ranging from 60 *Cyclops* to 31 *Bosmina*.

Sockeye Salmon Smolt Age and Size

Orzinski Lake sockeye salmon smolt were trapped during 07-21 June in 1994 and 12-30 June in 1995 (Appendix E). The peak smolt catch occurred in the last week of June for both years. There were 259 smolt sampled in 1994 of which 96.1% were age-2 and 1.9% were age-1 fish. Whereas in 1995 (n=198) the age structure shifted to 96.4% age-2 and 3.5% age-1 fish (Table 14). Smolt sizes were similar for both years; age-1 averaged 7.9 g and 89 mm in 1994 and 6.7 g and 87 mm in 1995. Age-2 smolt averaged 8.0 g and 96 mm in 1994 and 9.6 g and 99 mm in 1995.

Sockeye salmon smolt were collected at Sandy and Sapsuk Lakes for the first time in 1995 (Appendix E). Approximately 370 smolt were trapped at Sandy River from 26 June-18 July, with the peak catch occurring on 01 July. Of the 163 smolt sampled from the Sandy River catch, 100% were age-1, weighing 11.0 g with a length of 103 mm (Table 14). Of the 75 smolt captured at Sapsuk Lake during the week of 25 May, 90.6 % were age-1. These fish weighed 4.3 g and were 80 mm long. Age-2 smolt comprised 9.3% of the sample, and were 6.5 g and 94 mm in size.
Smolt trapping was conducted at Bear Lake during 31 May-03 August in 1993, 14 June-22 July in 1994, and 15 June-24 July in 1995. During these years, 4,393, 3,041, and 3,414 sockeye smolt were captured, respectively (Appendix Table E). The peak catches occurred in the second and third weeks of June. Of the sockeye smolt captured during these years (1993-1995), more than a 1,000 were sampled annually for age and size (AWL). The age composition of these fish was 89.1% age-2, and 9.8% age-1 smolt (Table 15). Historical data indicates that the predominant freshwater age class has remained two-year old fish from 1967 to 1995, excluding 1988 when the proportion of age-1 and age-2 smolt were equal (Table 15). In 1993, age-1 fish averaged 7.2 g, 90 mm in size compared to 1994 when they averaged 9.5 g and 99 mm. Likewise, age-2 smolt size increased from 9.1 g and 98 mm in 1993 to 12.0 g and 108 mm in 1994. In 1995, both age-1 and age-2 smolt were larger; age-1 averaged 11.5 g and 105 mm and age-2 averaged 13.7 g and 112 mm. Historically, the size of the dominant age class (age-2) of smolt has ranged from 15.9 g and 125 mm (1975) to 10.6 g and 90 mm (1968). In 1968, when age-2 smolt were smaller their condition (K) was the highest for all years (1.44). However, condition declined thereafter to a low of 0.65 in 1978, and then improved in the late 1980's. Overall, average smolt size and condition has been variable with no obvious long term trends (Figure 11). The variability in smolt size does not appear related to parent year escapement levels (Figure 12). That is, high and low adult escapements into Bear Lake produced smolts of similar size. On average, smolt size and condition has remained

robust, as indicated by 1994 and 1995 fish size and condition, and suggests a healthy juvenile rearing environment. However, these results should be interpreted with caution since sample sizes for all years have been relatively small.

Stream Blockages

Outlet streams at Red Cove, John Nelson, and Wosnesenski Lakes were evaluated by White et al. (1993) for obstructions to fish migration. The outlets of Red Cove as well as John Nelson Lake are oriented toward the open ocean, creating a high probability of stream blockage. In addition, the elevation of Red Cove Lake is only slightly greater than the average height of area high tides and often has no defined outlet channel as result of wave action. Thus, stream blockage is common as reported on 14 September 1992 when the outlet was effectively blocked by large, cobble-size, smooth surface rocks (White et al. 1993). This blockage was determined to prevent anadromous salmon migration and has not been permanently alleviated. However, fish may access the lake on the highest tides but migration success is unknown (Rod Campbell, ADF&G, Kodiak, personal communication). John Nelson Lake is essentially at sea level with a short outlet channel approximately 15 m wide by 60 m long at low tide (White et al. 1993). Debris often blocks the outlet creek but is often cleared by the caretaker at the Squaw Harbor processing facility. The outlet creek from Wosenesenski Lake has a low-gradient, well-developed oxbow type channel approximately 3 m wide by 390 m extending to the beach, and was blocked by driftwood timbers and logs (White et al. 1993). The blockage was significant and required substantial labor to clear. In 1994, a two to three person crew using chainsaws and come-alongs cleared debris from the creek (Rod Campbell, ADF&G, Kodiak, personal communication). This blockage was likely a one time occurrence and is not expected to impact anadromous fish migrations in the future.

Spawning Habitat Evaluation

Bear Lake tributaries Clear, Cub, and Red Creeks (Appendix A) were estimated to have a total of 103,502 m^2 of usable spawning habitat (Appendix F , The outlet creek was estimated to have 19,510 m^2 of useable habitat. Thus, total stream habitat is estimated to be 123,012 m^2 . In addition, we estimated 363,550 m^2 of spawning habitat in lake shoal (shore) areas. Based on an optimum sockeye salmon spawning density of one female per 2.0 m^2 (Burgner et al. 1969) the tributary and the lake outlet spawning habitats can support 51,752 and 9,755 female sockeye salmon, respectively. The shoal habitat is estimated to support an additional 181,775 females for a total of 243,282. Applying a 50:50 sex ratio would result in 486,564 sockeye salmon.

Sapsuk Lake tributary creeks (Voodoo, Happy Valley, and Red Bone; Appendix A) contained 31,580 m^2 of usable spawning habitat (Appendix G). The main tributary (Supper Creek) was not evaluated for usable spawning habitat; however, a foot survey of the creek was conducted in August 1993, and 10,000 sockeye salmon were estimated in the creek or holding near the creek mouth. Further investigations of Supper Creek are necessary to quantitatively determine the spawning capacity. However, based on observed spawning distribution, and creek dimensions relative to the other tributaries, a conservative estimate of useable habitat is 10,000 m^2. Thus, we estimate 41,580 m^2 of overall tributary habitat and an additional 246,800 m^2 of shoal spawning habitat for a total usable spawning habitat of 288,380 m^2. This equates to 144,140 females or overall (males and females), 288,000 spawners .

Sockeye Salmon Escapements, Timing, and Age Structure

The 10 year (1986-1995) estimated sockeye salmon escapements for 20 study lakes are summarized in Table 16, and for Bear River (1980-1995) in Table 17. Reliable escapement data for the remaining study lakes are unavailable.

Escapements into Orzinski Lake have ranged from a high of 40,000 (1991) to a low of 10,300 (1986), and averaged ~24,000 fish (Table 16). Since weir installation (1990), escapements have increased 26%, averaging ~ 29,000, with the three largest escapements (>30,000) occurring during the last five years (1991-1995). The average escapement during these years (~32,000) indicates an increasing trend; however, in 1995 escapement declined. The ADF&G desired escapement goal for this system is 20,000 (Shaul and Campbell 1996).

John Nelson Lake sockeye escapement has averaged 500 from 1986-1995, ranging from a high of 1,500 fish (1991) to a low of 0 (1986,1988; Table 16). The escapement has been cyclic in the 1990's; declining to 300 sockeye in 1993, then increasing to 1,100 in 1994, then declining by over 50% in 1995 to 500 sockeye. The escapement goal range has not been defined for this system.

The escapement into Acheredin Lake has averaged 4,070 sockeye salmon (Table 16). The largest escapement from 1986-1995 was 7,100 sockeye in 1989 and 1994, while the lowest was 800 sockeye in 1992. The 1995 escapement (3,900) was close to average. The escapement goal range has not been defined for this system.

Mortensen Lake escapement has ranged from a high of 14,100 in 1991 to a low of 1,400 in 1986 (Table 16). The average escapement is 6,840 fish. The largest escapements occurred in the past five years (1991-1995); however, since 1992 escapement has declined by ~ 40%. The escapement goal range for this system is 3,200-6,400 sockeye salmon (A. Shaul, ADF&G, personal communication).

Sockeye escapements into Thin Point Lake from 1986-1995 have ranged from 40,600 (1991) to 10,400 (1987), averaging ~25,000 (Table 16). Escapements have been cyclic with peaks about every third year. The 1995 escapement (~32,000) was the second highest in the last ten years, exceeding the escapement goal range of 14,000-28,000 fish (Shaul and Campbell 1996).

Morzhovoi Lake (Middle Lagoon) escapement has ranged from a high of 40,700 in 1995 to a low of 5,500 in 1986 and has averaged 18,900 fish (Table 16). The escapement increased from 1986 to 1990, then decreased until 1993. The average escapement from 1993-1995 is ~30,000, a 36% increase from the overall average and near the desired escapement goal of 32,800 fish (Shaul and Campbell 1996).

Charlie Hansen and Swede's Lakes escapements have been on the decline, since peaking in 1992 (6,400) and 1990 (2,000), respectively, and have averaged only 1,567 and 590 fish each (Table 16). The lowest escapement estimates were 50 fish at Charlie Hansen Lake in 1987, and 100 fish at

Swede's Lake in 1994. These estimates are based on limited aerial surveys, so they should be regarded with caution. However, when surveys were improved in 1994 and 1995 only 1,000 sockeye salmon were estimated at Charlie Hansen Lake. The desired escapements goals for these systems are 800 (Charlie Hansen) and 1,200 (Swedes) fish, and are low due to spawning habitat limitations (A. Shaul, ADF&G, personal communication) .

Escapements at Ilnik and Sandy Lakes have been similar in magnitude, ranging from highs of 135,000 (1991) and 125,000 (1995) to lows of 15,000 (1989) and ~7,000 (1986); average escapement is ~52,000 and ~55,000, respectively (Table 16). In recent years (1991-1995), escapements have increased, averaging ~73,000 and ~84,000. The escapement goal for each system is 40,000-60,000 sockeye salmon (Murphy and Shaul 1996), which has been exceeded at Ilnik three of the past five years and for the last two years at Sandy River. In fact, escapement estimates increased, on average, by ~35% at Ilnik, and ~145% at Sandy Rivers once weirs were employed to count salmon (Table 16).

Wildman Lake and Willie Creek are part of the Ilnik Lake system. Sockeye escapements to these systems have averaged (1986-1995) 25,920 and 12,125, respectively (Table 16). Generally, escapement trends at these systems parallel the Ilnik Lake weir counts. That is, the largest escapements at both systems (99,000 and 29,250) occurred in 1991 when the largest escapement occurred at Ilnik (135,000). Similarly, the lowest escapements (200 and 4,125) occurred in 1989 when Ilnik escapement was only 15,000 sockeye.

Nelson River escapements from 1986-1995 ranged from a high of 329,400 (1995) to 117,000 (1986), averaging 208,350 (Table 16). Escapements have exceeded the goal of 100,000 to 150,000 in seven of the last 10 years; most noticeably in 1994 and 1995 when escapements were over double the desired goal (Murphy and Shaul 1996). Escapements specific to Sapsuk Lake are unavailable.

From 1986-1995, Southwest Lake escapement has ranged from 4,000 (1992) to 0 (1986), averaging 1,710 sockeye (Table 16). The 1994 escapement (400) was the lowest since 1986; however, in 1995 escapement was only slightly below average at 1,400 sockeye. Escapement goals have not been delineated for this system.

Big Fish Lake escapement has averaged 4,670 sockeye from 1986-1995 (Table 16). The high was 14,500 sockeye in 1990 while the low was 1,400 sockeye in 1989. The 1995 escapement was considerably less than the average at 2,800 sockeye. Escapement goals have not been delineated for this system.

Since 1980, Bear River sockeye salmon escapement has varied considerably. Escapements have ranged from 700,000 (1980-81) to less than 300,000 (1986-87), averaging 433,600 (Table 17). Since 1985 when weir enumeration began, the escapement has averaged 413,500. If delineating early run from late run fish, similar variability has occurred. The highest early run escapement occurred in 1981 (475,000) whereas the late run high was in 1990 (263,000). The lowest early run escapements occurred in 1982 (105,000) followed by 1983 (158,000). The early run escapement has averaged 266,000 fish compared to 168,000 for the late run. The escapement goal range of 200,000 to 250,000 (Murphy and Shaul 1996) has been exceeded each year during this period.

Sockeye salmon escapement data are incomplete for Unalaska Island systems; however, available data (1986-1995) indicates that Kashega Lake is the largest producer with an average escapement of 7,267 sockeye (Table 16). McLees and Volcano Lakes are the next largest producers, averaging and escapement of 2,690 and 2,433 sockeye, respectively. Summer Bay and Unalaska Lakes have produced low sockeye numbers, with average escapements of only 450 and 98 sockeye, respectively.

Sockeye salmon return to Alaska Peninsula systems from June through September (Murphy 1992). The peak escapements occur from late June, early July (Nelson River, Ilnik and Sandy); mid-July (Orzinski); to mid to late August for Cold Bay area systems (Murphy et al. 1995; McCullough et al. 1995). The Bear River sockeye salmon run is bimodal; an early run returns in early June, peaks in early July, and ends in late July and a late run begins in late July, peaks in early to mid August and ends by mid to late September (Murphy 1995). Unalaska Island sockeye salmon runs, generally, are early, beginning in mid to late May, peaking in late June, ending in late July (P. Holmes, personal communication, ADF&G, Kodiak).

From 1990-1995 sockeye salmon escapement to Orzinski Lake were comprised, on average, primarily of four and five-year old fish (Table 18). Specifically, 32.3% were age-1.2, 5.5% were age-2.1, 22.6% were age-1.3 and 17.7% were age-2.2. Six-year old fish were the next dominant age class with 15.5% age-2.3 fish.

Thin Point Cove sockeye salmon escapement (1989, 1993, and 1995) were comprised mainly of five-year old fish (Table 19). The primary age class was 1.3 (50.7%) with a smaller number of 2.2 -age fish (7.5%). Four and six-year old fish dominated the remainder of the escapement with 25.6% 1.2-age fish, 2.2% 2.1-age fish and 11.3% 2.3-age fish.

In 1995, Middle Lagoon (Morzhovoi Lake) sockeye escapement were comprised of four-year old (1.2-age) fish (55.1%; Table 20). Five-year old fish were the next dominant age and were comprised of 34.8% 1.3-age fish. In addition, 7.2% of the escapement were 0.3-age sockeye.

From 1989-1995 Ilnik River escapement averaged 62.6% five year-old sockeye which were primarily age-1.3 (61%) with a minor component of age-2.2 (1.6%) fish (Table 21). Four -year old sockeye comprised 17.7% of the escapement of which 7.8% were age-0.3 and 9.8% age-1.2. Six-year old sockeye (age-2.3) comprised 11.6% of the escapement. The overall proportion of age-0.x sockeye was ~ 8%.

The predominant age of the average of Sandy River escapement for 1989, 1994, and 1995 were age-1.2 (53.7%) or four-year old sockeye (Table 22). Five-year old sockeye (age-1.3) comprised 40.1% of the escapement. Other ages represented included 2.3% age-2.2 and 2.1% age-1.1.

Bear River escapement from 1986-1995 was primarily five-year old sockeye (Table 23). The majority (55.2%) were age-2.2 with a small number (5.6%) of age-1.3 sockeye. The next dominant age class was six-year old (age-2.3) sockeye comprising 26.4% of the escapement. In addition, 7% of the escapement were age-2.1 sockeye and 3.9% age-1.2 sockeye.

Escapement at Nelson River from 1986-1995 was predominantly five-year old sockeye of the 2.2 age-class (58.2%; Table 24). Approximately 8% of the five-year old sockeye were age-1.3. Six-year old fish (age-2.3) comprised 19.4% of the escapement. Four-year old sockeye were also present with 8..9% age-1.2 and 4.2% age-2.1.

Relationship of Sockeye Salmon Escapement to Limnological Variables

As limnological variables are linked to freshwater production and ultimately stock production, we were interested in which of the limnological variables were related most to sockeye production in the 23 study lakes. Although we lacked system specific sockeye harvest data, we assumed a constant harvest rate and considered sockeye escapement as a surrogate for total production. That is, systems with higher escapement should produce more fish than those with a lower escapement. For the 11 lake systems in which we had historical and reliable escapement information, we regressed morphometric, trophic status, and zooplankton variables against mean (1986-1995) sockeye escapement (ESC). There was no significant relationship between ESC and euphotic zone depth (EZD), total phosphorus (TP), chlorophyll (CHL), and zooplankton biomass (TMZB). However, we found significant relationships between ESC and mean depth (Z), surface area (SA), and euphotic volume (EV). When all lakes (N=11) were considered, Z accounted for 74% of the variation in ESC (Figure 13A). The regression equation was ESC = 1,880 + 7,858Z (F=24.9; P=0.001). However, the variation explained by the regression model was largely determined by two points, Bear and Sapsuk Lakes, the deepest of the study lakes. When these lakes were excluded from the regression analysis, there was no significant (F = 0.36; P=0.57 relationship between ESC and Z (Figure 13B). Moreover, ESC appeared inversely related to Z. Thus, for shallow (Z <8 m) lakes, which characterize most of the lakes in this study, ESC was not functionally related to Z.

Since Wildman Lake empties into Ilnik Lake a proportion of the Ilnik system escapement includes that for Wildman Lake. Therefore, we combined the surface areas and euphotic volumes for these two lakes. Hence, the number of lakes in the statistical analysis was reduced to 10. We found a positive relationship between ESC and SA (Figure 14A). The regression equation was ESC = -45,771 + 10,485SA; r^2 = 0.40. The slope of the regression line was marginally significant (F=5.2; P=0.05) and the variation was quite large. The data corresponding to the two deep lakes (i.e. Bear and Sapsuk) deviated most from the regression line. When these lakes were excluded from the model (N=8), we derived a very different relationship (F=13.8; P=0.01) (Figure 14B). The regression equation was ESC = -2,472 + 2,370SA; r^2 = 0.70. Although the data are few (n=8), the points were fairly well distributed along the regression line. However, because of the large y-intercept, the model predicted a negative ESC for very small lakes. Since the intercept was not statistically significant (P=0.77), we applied a 0-intercept model. This regression equation was ESC = 2,203SA (r^2 = 0.69). We also derived a significant (F=513.1; P<0.001) linear relationship between EV and ESC (Figure 14C). The regression equation was ESC = -11,350 + 1,058EV; r^2 = 0.99. Despite the significance of the regression slope, the shallow lakes were clustered at the low end of the regression line; Bear and Sapsuk Lakes were located at the high end of the range. When the two deep lakes were excluded from the model (N=8), we derived a significant (F=13.5; P=0.01) relationship with a slightly lower slope. The regression equation was ESC = -3,660 + 850EV; $r^2 = 0.69$ (Figure 14D). Thus, both SA and EV explained the same amount of variation in ESC.

Bear Lake Sockeye Salmon Return Per Spawner

Although the Bear Lake sockeye run is comprised of an early and late component, return-per-spawner (R/S) data are only available for the late run. The return of late run Bear River fish has ranged from over one million (1987 and 1989 parent years) to 281,000 (1982 parent year) for nine (1980-89) fully recruited brood years (Table 17). The average late return during this period has been 662,530; however, it has increased to 931,535 fish during 1985-89. The largest return per spawner (R/S) was 13.05 as result of the smallest escapement (83,395) in 1987 compared to the smallest R/S of 1.48 as result of the third largest escapement (214,000) in 1981 (Figure 15). The average R/S is 5.05 during 1980-1989 and 7.50 during 1985-1989 (Murphy 1995).

The late run escapement represents about one-third of the total escapement. A plot of the annual escapement reveals that both early and late run components fluctuate for the most part in concert (Figure 16A). Hence, we assumed the late run R/S estimates to be the same for the early run. We then regressed R/S against the total number of spawners (S). The regression model was ln R/S = 2.5459 - 0.0028S ($r^2 = 0.40$) (Figure 16B). The slope was marginally significant (P=0.05). The relationship showed that R/S decreased with an increase in the number of spawners. For the total run, the number of spawners to maximize yield was estimated at 305,000 which is very close to the current escapement goal of 250,000.

Brood Source Surveys

The main tributary on the north shore of Orzinski Lake was surveyed by foot on 09 August, 1993 (Appendix A). The creek contained ~200 pinks and five sockeye jacks, all within the first ~180 m of the creek. The survey was continued for approximately 1.5 km upstream with no live or dead fish observed. Presumably, the survey was conducted too early to observe stream spawners which were likely staging in the lake. Sockeye salmon were observed spawning along the lake shore, however, abundance was not estimated.

Sockeye salmon spawning along the shore line of Orzinski Lake were screened on 09 August 1993 for detection of the IHN virus and BKD. No indication of the IHNV or Renibacterium salmoninarum (BKD) was found in 64 samples. (Appendix H).

Voodoo Creek, a Sapsuk Lake tributary located near the southeast portion of the lake, was surveyed (also on foot) on 10 August, 1993 and contained no sign of fish. When surveyed, approximately 2,000 sockeye salmon were holding in the lake at the creek mouth, possibly staged for spawning in this creek. A series of ponds adjacent to Voodoo creek were being utilized by 500 spawning sockeye salmon and an additional 800-1,000 were observed staging in the lake, presumably destined for these ponds. When surveying Supper Creek (Sapsuk tributary), approximately 6,500 sockeye salmon were estimated as well as an additional 1,000 fish staged at the lake. Less than six km of the creek was surveyed by foot. Aerial survey estimates of the remainder of the creek indicated an additional 3,000-3,500 fish. Shore spawning was observed along a majority of the lake shore; however, no estimates were made.

Sockeye salmon from the shore line of Sapsuk Lake near Supper Creek (Appendix A) were sampled to test for incidence of the IHNV and BKD. Sixty ovarian and kidney samples were collected on 16 August, 1993. Of the fish sampled for IHNV, 39 of 60 fish (65%) tested positive for the virus (Appendix H). Of the 39 ovarian fluid samples, nine had IHNV titer levels 10^4 or greater. Testing for BKD revealed that 8 of 60 samples (13.3%) were positive for Renibacterium salmonarium .

Mortensen Lake sockeye salmon were screened in September 1987 and 1988 for disease incidence (ADF&G, unpublished data). Of the samples collected, 38% (1987) and 5% (1988) tested positive for the IHN virus and no fish were positive for BKD.

Testing for BKD incidence in adult coho salmon from Russell Creek located near Cold Bay (Figure 1) was conducted in September, 1994. BKD was not detected in 57 samples (Appendix H). Also, BKD samples taken from John Nelson (1993) and Mortensen Lake coho salmon (1987) were negative for BKD.

DISCUSSION

Of particular interest to fishery scientists and managers is the ability to predict the quantity of fish in a particular waterbody. Various physical, chemical, and biological indices have been used to estimate fish biomass in lakes and reservoirs in many geographic regions throughout the world (Peters 1986). However, lakes are notoriously individualistic and complex (or confounding) in their expression of trophic status (Carlson 1977), plankton dynamics (McCauley and Kalff 1981; Pace 1984; Schmidt et al. 1994), and food web interactions (Carpenter and Kitchell 1993). As a group, the 23 Alaska Peninsula-Aleutian Islands lakes are no exception in that they exhibit a wide range of limnological conditions. For example, many of these lakes are small (surface area <1.0 km^2) and shallow (mean depth<2 m) whereas others, such as Bear and Sapsuk Lakes, have immense volume (Table 2). The underwater light in some lakes is regulated by both inorganic (re-suspended bottom sediments) and organic (phytoplankton) turbidity (Figures 3 and 4). Despite the high light attenuation, most of the water column in shallow systems (mean depth <8m) is photic (Table 3). Some of the lakes are considered eutrophic with very high phosphorus concentrations and algal (chlorophyll) densities (Figure 9) while others are nutrient starved (phosphorus limited) having very low algal biomass levels. Several lakes support large populations of zooplankton e.g., Wildman, Bear, and Sapsuk Lakes, but in more than half of the lakes there is a paucity of forage (zooplankton biomass) available to planktivorous fish (Tables 9, 10 and 11). Three of the lakes are saline or brackish from natural inputs of seawater (Table 6), exhibit hypolimnetic oxygen depletion (Figures 6 and 7), and contain a mixture of freshwater and marine associated fauna (Table 9). Given the diversity of lakes, we attempted to model sockeye escapement data with various limnological characteristics as a first step in providing a tool for evaluating potential sockeye production in the Alaska Peninsula study lakes. A multi-lake comparison of limnological features versus salmon population characteristics is fundamental to both fishery management and enhancement rationale.

Limnology Relative to Potential Fish Production

One of the earliest limnological characteristics used in assessing productivity was morphometry. The size and shape of the lake basin was hypothesized as being an important factor in controlling nutrient supply and ultimately productivity. Mean depth (Z) and commercial fish production were found to vary inversely among the Great Lakes and several other lakes in central Canada (Rawson 1955). Northcote and Larkin (1956) also found a negative curvilinear relationship between mean depth and the average weight of fish gillnetted among a wide variety of British Columbia lakes. In contrast, we found a direct relationship between relative fish biomass which we define here as average sockeye escapement (ESC) and Z (Figure 14). However, the relationship was entirely driven by the two deepest lakes (Z >30 m; i.e., Bear and Sapsuk Lakes; Figure 14A). We feel that it is not an appropriate measure of relative fish production in shallow lakes (Figure 10B).

Rounsefell (1946) found an inverse relationship between fish yield and surface area (SA). That is, large lakes produced less fish per unit area than small lakes. Among our lakes, escapement was correlated with SA (Figure 15A), but when only the shallow lakes were considered the regression model had a much lower slope (15B). We interpret this to mean that on an areal basis, shallow lakes (Z<8 m) produce less fish than deep lakes. Our 0-intercept model predicts an ESC of 2,203 per km^2. Assuming a 40% harvest rate (Koenings and Burkett 1987a), this equates to a total return of ~5,500 sockeye km^{-2}. SA is also a component of euphotic volume (EV). Koenings and Burkett (1987) developed the first production potential model specifically for sockeye salmon using EV. They described a positive relationship between EV and sockeye production for a number of Alaska lakes. This regression forecasts 2,300 adult sockeye per EV unit (10^6 m^3). Considering the Alaska Peninsula lakes, ESC was directly related to EV ($r^2 = 0.99$), but the data plot revealed that Bear and Sapsuk lakes were highly influential and responsible for the large r^2 value (Figure 15C). Among the shallow lakes ESC was also strongly correlated with EV ($r^2 =$ 0.70). This model predicts an ESC of 850 sockeye EV^{-1} (Figure 15D). Assuming a 40% harvest rate (Koenings and Burkett 1987), this equates to a total adult production of 2,125 EV^{-1} which is a very similar to the Koenings and Burkett model prediction (2,300 EV^{-1}). Although EV had the same predictive power as SA (r^2=0.70), using SA may be more appropriate for assessing potential production in shallow lakes, whereas the EV model is more appropriate for deep lakes.

Ryder (1965) devised the morphoedaphic index or MEI, calculated as the total dissolved solids concentration (or conductivity) divided by mean depth, and derived an empirical relationship between MEI and potential fish yield for northern Ontario lakes. MEI was subsequently used to estimate fish production in various lakes and reservoirs (Ryder et al. 1974; Oglesby 1977; Prepas 1983; Chow-Fraser 1991). The rationale for MEI is that the nature of the surrounding watershed largely determines the amount of total solids (minerals) entering the lake, which is assumed to be proportional to the concentration of dissolved nutrients (nitrogen and phosphorus). Mean depth affects water residence time, influences thermal and light regimes, and regulates nutrient recycling (Wetzel 1975). Thus, MEI integrates soil and hydrologic conditions of the drainage area and represents an index of potential productivity. We too considered MEI (conductivity/Z) and found no relationship. It is known that the use of MEI to predict fish yield for an individual lake is more appropriate when comparing lakes of similar size because fisheries in smaller lakes are exploited more efficiently than in large lakes (Ryder et al. 1974). MEI is also a better predictor of fish yield when lakes in the data set are of a comparable water type (Matuszek 1978) and subject to similar climatic conditions (Schelsinger and Riger 1982). In our lakes, the lack of correlation between ESC and MEI was not entirely unexpected given the wide diversity in limnological conditions and the large number of shallow lakes.

There is ample evidence that fish yield or biomass is highly dependent upon nutrients and primary productivity. Hrbacek (1969) derived a positive relationship between fish yield and Kjeldahl nitrogen concentration in small European ponds. TP explained 80% of the variation in fish standing crop among a variety of north-temperate lakes (Hanson and Legett 1982). Quiros (1990) excluded lakes which were shallow, had low N:P ratios, and those with inorganic turbidity as atypical and derived a significant relationship between catch per unit effort (CPUE) and both TP (r^2 = 0.73) and organic nitrogen (r^2 = 0.69). In temperate lakes, fish yield or biomass is also positively related to photosynthetic rates (Melack 1976; McConnel et al. 1977; Oglesby 1977; Stockner 1987) and phytoplankton (algal) standing crop (Oglesby 1977; Jones and Hoyer 1982). Among our study lakes, we found no functional relationship between ESC and either nutrient (TP and TN) concentration or CHL. It is known however that the contribution of nutrients from run-off can be more significant in a small shallow lake compared to a large deep lake (Hutchinson 1957; Wetzel 1975; Vollenweider 1976; Cooke et al. 1993). That is, shallowness promotes eutrophy as evidenced by the very high TP concentrations and chlorophyll levels in several of our lakes (Tables 4 and 7). On the other hand, large lakes such as Bear and Sapsuk lakes tend to be less susceptible to nutrient accumulation because of dilution effects (i.e. a large volume) and therefore have a lower algal standing crop. Thus, the lack of response between ESC and nutrient variables and algal biomass may be related in part, to fundamental differences in nutrient loading, re-cycling, and productivity between deep and shallow lakes.

Other biotic variables have been used to predict relative fish biomass in various lakes and reservoirs. Hanson and Legget (1982) correlated fish standing crop to the macrobenthos biomass:mean depth ratio in several north-temperate lakes. Borgmann et al. (1984) incorporated an index of biomass conversion efficiency and annual zooplankton production to estimate potential fish yield in Lake Ontario. Recently, Luecke et al. (1995) determined zooplankton biomass to be the most appropriate measure of potential sockeye production for several sockeye nursery lakes in the Snake River drainage. Koenings and Kyle (1991) derived a significant relationship between sockeye smolt biomass and zooplankton biomass for 16 Alaskan lakes. Relating ESC with TMZ biomass proved unsuccessful for our data set. However, both Bear and Sapsuk lakes are of similar type (deep, oligotrophic) to the lakes used in the Alaskan zooplankton biomass model. Therefore, we considered the Alaskan zooplankton biomass model appropriate to apply to Bear and Sapsuk lakes.

Given the average size (8 g) age-1 smolt for Bear Lake (Table 15) and the average TMZ biomass (1,847 mg m^{-2}), this model predicts that this lake could produce ~12 million smolt. If we assume a 20% smolt to adult survival (Koenings and Burkett 1987a), then based on the amount of forage, Bear Lake is estimated to produce ~2.5 million sockeye adults. This projection is similar to what our Ricker analysis predicts for a total return (1.96 million) as result of escapement (~300,000) for maximum sustainable yield (Figure 16B)). For Sapsuk Lake, which also produces large sized age-1 smolt (4.3 g) and has abundant zooplankton (mean 944 mg m^{-2}), the zooplankton model predicts a total of 2.4 million smolt which translates to ~480,000 adult sockeye. This figure is very close to a production estimate (520,000) based on the average escapement (208,000) and a 40% harvest rate. It should be stressed that the Alaskan zooplankton model (Koenings and Kyle 1991) assumes that the lakes are at or near rearing capacity; however, predictions of smolt biomass are based upon current zooplankton levels which may or may not reflect abiotic (environmental) or biotic (planktivory or predation) conditions in subsequent years. Thus, predicted juvenile carrying capacity and actual smolt production can differ. With the exception of Wildman Lake which was very shallow, none of the other lakes have appreciable zooplankton biomass levels. Hence, based solely on zooplankton, Bear and Sapsuk lakes have the highest sockeye production potential.

Fishery Assessment Relative to Salmon Production

Sockeye smolt data are sparse with the exception of annual sampling for condition at Bear Lake. Several trends from this assessment are of interest. For example, sockeye salmon smolt emigrate from Bear Lake predominantly as age-2 fish (~90%) rather than age-1. Schmidt et al. (1996) suggests that at Karluk Lake, a bimodal (early and late run) sockeye salmon system on Kodiak Island, late emergence of fry is timed with summer cladoceran blooms that provides sufficient nutrition for overwintering and an competitive advantage the following spring. This may, in turn, result in continued hold over for one to two years prior to smolting. The freshwater life history of (early and late run) juveniles rearing in Bear Lake may be similarly timed to peak zooplankton. However, smolt sizes are robust and forage levels may be underutilized. Extrapolating from a predicted 12 million smolt production based on zooplankton biomass and a 20% fry-to-smolt survival, results in a spring fry recruitment of ~63 million. In comparison, an escapement level of 300,000 is estimated to produce ~26 million spring fry (50:50 sex ratio; 2,500 fecundity; 7% egg-to-fry survival [Bradford 1995]), or less than half of potential based on zooplankton.

Escapement age analysis revealed that Ilnik River and Middle Lagoon (Morzhovoi Lake) sockeye are comprised of a component of age-0 or underyearlings. The proportion of underyearlings, however, varies from year to year at Ilnik as indicated by 1994 and 1995 escapement sampling when ~37% and ~16% were 0-checks, respectively (Nelson and Murphy 1995b; Nelson and Murphy 1996). Middle Lagoon had only ~8% underyearlings in 1995. Both systems, although extremely shallow and containing little zooplankton, are dominated by age-1.2 or age 1.3 sockeye. Thin Point Lake, which is also shallow with virtually no zooplankton, has not contained any 0-age sockeye in escapement samples and is dominated by 1.3 fish. This indicates that sockeye juveniles in these systems rear in the lakes and likely utilize food sources other than zooplankton. This would also suggest that winter dissolved oxygen levels are sufficient for rearing; however, perhaps may fluctuate seasonally or annually affecting survival. Additional study is warranted to further delineate the underyearling production parameters of these sockeye runs and assess dissolved oxygen regimes as related to overwinter survival .

Orzinski Lake sockeye smolt age structure shifted from a predominance of age-2 (96%) in 1994 to primarily age-1 fish in 1995 (96%). The 1994 age structure may be a result of the large 1991 brood year escapement (40,000) which was double the escapement goal (Table 16). Increases in the amount of holdover smolt (age-2 and 3) can indicate a less than optimum rearing environment (Koenings and Burkett 1987a; Barrett et al. 1993), thus, additional smolt data are need to determine if the age structure remains as in 1995 or reverts back in years following large escapements.

The measurement of salmon spawning habitat provide estimates of spawning capacity (Kyle and Honnold 1991; Honnold and Edmundson 1993; Willette et al. 1995) and aids in the setting and evaluation of escapement goals. Inventorying habitat is a common practice with many sampling designs available (Swanton et al. 1993). Recent studies have focused on estimating the size of resident fish populations and impacts of land use practices (Platts et al. 1983; Frissel 1986; Murphy et al. 1987; Hankin and Reeves 1988). Other studies have emphasized salmonid spawning habitat evaluation by way of classification of habitat units (Hankin and Reeves 1988) and substrate size (Shirazi and Seim 1979). Raleigh and Nelson (1985) developed a habitat suitability model, in which substrate size and water velocity were primary factors of spawning success for pink salmon. Substrate embeddedness is also considered important (Chambers et al. 1955; Platts et al. 1983). These direct measures of spawning habitat are alternatives to indirect classification methods (Swanton et al. 1993). It may be more appropriate to combine direct with indirect measures as reported by Swanton et al. (1993) and Willette et al. (1995) in studies on Kodiak Island. On Afognak Island, habitat assessments have used combined methodology to estimate sockeye salmon spawning capacity or optimum escapements for specific habitats (Kyle and Honnold 1991; Honnold and Edmundson 1993; White and Edmundson 1993). That is, tributary habitat was directly measured for area, then assessed for potential use based on criteria as described by Chambers et al. (1955). Lake shoals were measured indirectly by planimetry of a bathymetric map; combined with spawner distribution trends, was used to assess potential use . Once the useable area was defined then the number of female sockeye salmon per unit area (1.0/2.0 m^2; Burgner et al. 1969) was estimated. The methodology used on Afognak Island was applied to Bear and Sapsuk Lakes tributary and lakeshore habitat.

Average escapements (434,000) into the Bear Lake system are not exceeding spawning habitat capacity (487,000). The stability of the smolt sizes, particularly from high parent year escapements indicates the system is spawning habitat limited. The analysis of R/S data indicates decreased returns with increased escapement. A total escapement of 305,000 sockeye is estimated to maximize yield and produce returns of approximately 1.9 million adults. Sapsuk Lake habitat is also estimated to support more sockeye salmon (288,000) than the average Nelson River escapements (208,000). If we assume the majority of fish enter Sapsuk Lake, then spawning habitat would be under utilized. However, recent Nelson River escapements (1994-1995) have been in excess of 325,000 fish, thus spawning capacity may have been exceeded if the majority of these fish spawned in Sapsuk Lake habitat.

These estimates of available habitat, however, are not without limitations. That is, lakeshore (shoal) estimates were primarily derived indirectly (planimetry) compared to tributary estimates which were delineated directly by field measurements. In addition, estimates of useable proportions of habitat, although based on definitive criteria, are also subject to bias inherent when working in field conditions. Generally, conservative estimates were used to determine the proportion of useable habitat. However, lakeshore habitat measurements may be high as reflected by the large proportion (75% for Bear Lake and 88% for Sapsuk Lake) of the total habitat. It would be prudent to conduct additional assessment to supplement this initial habitat evaluation.

Escapements increased at Ilnik and Sandy Rivers after weirs were installed. These increases indicate that aerial escapement estimates (indexed) are biased low. Thus, some estimates of total escapement for the study systems may be conservative. Although aerial survey counts are likely biased low, historical abundance trends can be discerned from these data. For example, if comparing five year average aerial indexed escapements from 1971 to 1985 with the escapement estimates from 1986 to 1995, most systems have had increased abundance in the 1990's at (Figures 17-23). Small systems such as Acheredin, Swedes, Big Fish, Southwest, Summer Bay, McLees, and Volcano Lake have had decreased abundance of sockeye salmon. Orzinski Lake escapements were stable (~20,000) from the early 70's through the early 80's, then declined slightly in the mid 80's, and since have been steadily increasing (Figure 17). The five-year average escapements at John Nelson Lake have also increased in the 1990's. By comparison, the Cold Bay Lakes (Thin Point and Morzhovoi) experienced increased escapements in the late 70's, a decline in the early 80's, and then a large increase from 1985 to 1995 (Figure 19). Mortensen Lake has had similar trends; however, at a much lower magnitude of change and marginal increases in recent years. Average sockeye salmon escapements into Charlie Hansen and Swedes Lakes were very low from the 70's through mid 80's with an increasing trend at the former and a declining trend at the latter in the last five years (Figure 18). Escapements at the smaller northcentral systems (Ilnik and Sandy) were similar to the larger systems (Bear and Nelson Rivers), from 1975 to 1985 with steady increases occurring until the early 80's (Figures 20 and 21). The declining trend was less pronounced at Nelson River during this period. While Bear, Nelson, and Sandy Rivers escapements continued to slowly decline in the late 80's, Ilnik River's escapements increased and continued this trend into the mid 90's when the average (five year) escapement reached an all time high. Since 1990, average escapements at Bear and Nelson Rivers have increased; however, at a slower rate than Sandy River which has experienced record highs in the past several years. Again, the increased escapement at Sandy and Ilnik Lakes may be related to methodology (weir counts), and may explain the high five year average. Of the Unalaska Island sockeye systems, only Unalaska and Kashega Lakes have higher five-year average escapements in the 1990's (Figure 23).

Coho Salmon Production and Interspecies Competition

Coho salmon production data for the Alaska Peninsula and Aleutian Island regions is, at best sparse. Historical escapement data has not been collected at most systems due to ADF&G budget constraints limiting weir operation and aerial surveys. In addition, weather patterns during peak run timing and escapement periods are not conducive to aerial surveying (Murphy 1995). However, anecdotal evidence as well as some weir counts and aerial surveys indicate that the majority of systems have coho runs (James McCullough, ADF&G, Kodiak, personal communication). In 1990, increased effort enabled more thorough coho salmon escapement estimates than usual (Murphy 1995). These surveys indicated that Nelson River (Sapsuk Lake), Ilnik Lake, and Meshik River, are significant producers, with Swanson's Lagoon, Thin Point Lake, Mud Creek, Mortensen Lake, Russell Creek, and Orzinski Lake also producing coho salmon (Shaul et al 1991; Appendix I). Port Heiden, Unangashak River, Joshua Green River, Christianson Lagoon, and Cinder River are also reported to have healthy runs of coho salmon. These systems are located on the North Peninsula with the exception of Thin Point Lake, which is the largest South Peninsula coho salmon system. All of these systems produce sufficient coho salmon to provide site specific commercial harvest. Many other systems produce coho including Bluff Creek, Reindeer Creek, Sandy River, Bear River, King Salmon River, North Creek, Middle Lagoon, Kivzarof Lagoon, Delta Creek, Canoe Bay River, Settlement Point Creek, Mino Creek, Beaver River, Lefthand River, Dry Lagoon, and Squaw Harbor Creek.

Coho salmon production potential in other areas has been estimated based on physical characteristics, morphemetry, light penetration, and other biological properties (Crone 1981; V. Litchfield, ADF&G, personal communication, Soldotna). Some important aspects of such modeling include surface area, littoral zone definition (area and volume), and euphotic volume (EV). In addition, the prior years (recruitment) history of juvenile rearing and food habits as they are linked to smolt production are essential to estimate coho fry carrying capacity.

Based on morphometry, those study lakes with the largest proportion of euphotic volume (EV) compared to total volume (TV) would likely be the best coho salmon producers. That is, the closer the EV/TV ratio is to one, the more EV by unit volume available for coho production. The majority of shallow and intermediate depth lakes have such an EV/TV ratio (Tables 2,3 and 25). Of these lakes, only Acheredin, Big Fish, Wildman, Red Cove and McClees have an EV/TV ratio less than one. However, based on morphometry, all likely would produce coho. Bear and Sapsuk Lakes have the lowest proportion of EV, but with their large total volumes, also would be expected to produce coho.

Coho salmon rear in John Nelson, Thin Point and Morzhovoi Lakes as indicated by the capture of juveniles while beach seining. These fish were in good condition and fed primarily on insects. Coho in Thin Point and Morzhovoi Lakes fed primarily on insects and secondarily on zooplankton.

Diet information is important to determine habitat use by coho salmon juveniles as well as assessing interspecific competition with sockeye salmon juveniles. Coho salmon juveniles have been reported to exert heavy predation pressure on littoral rearing sockeye fry. Beauchamp (1995) cited numerous studies that have observed predation as a contribution of sockeye salmon mortality during fry emergence and migration (Ruggerone and Rogers 1992), lake residence (Eggers et al. 1978); Beauchamp et al. 1992, 1994) and smolt migration (Rogers et al. 1972; Ruggerone and Rogers 1984). In Chignik Lakes, coho smolts were observed to be substantial predators on sockeye fry (Ruggerone and Rogers 1992). During the lake rearing phase, if predation on sockeye fry is found to be significant, alternate enhancement strategies may be necessary; either to manage the piscivore abundance or to produce enough sockeye to enable absorbing the loss to predators (Beauchamp 1995). In 1994, Thin Point and Morzhovoi Lakes coho salmon stomach's contained primarily insects and mysids which are commonly found in nearshore areas. There was no evidence of coho predation on sockeye fry from stomach contents. John Nelson coho salmon juveniles preyed on zooplankton secondarily to amphipods, mysids, and insects (Appendix D). Mason (1974) found that dipteran insects were by far the most important food source for coho salmon in a Great Central Lake, and composed more than 80% of the coho diet, however zooplankton were also consumed throughout summer months. Crone (1981) found in study lakes in southeast Alaska that if zooplankton were abundant coho salmon were found offshore feeding, whereas at low zooplankton densities, feeding occurred mostly inshore on insects. Studies in Bear Lake (Kyle 1990) revealed that zooplankton provide an important food source for rearing coho salmon juveniles that can be primary or secondary to insects. The presence (or absence) of zooplankton can potentially influence growth and rearing behavior of juvenile coho salmon. Thus, at John Nelson there may be interspecies (coho and sockeye salmon) competition in the limnetic zone for zooplankton, while competition may be less prevalent at Thin Point and Morzhovoi Lakes. Additional diet information should be collected at other Alaska Peninsula and Unalaska systems to determine diet trends and the extent of interspecies competition. Lastly, river and stream habitat should be assessed for coho rearing capacity.

Techniques to Increase Salmon Production

The simplest, most cost effective technique to increase salmon production may be aggressive fisheries management. Achieving maximum sustained yield (MSY) is most often the goal of salmon fisheries managers. Traditionally, escapement goals and management strategies have focused on spawner-recruit curves such as those modeled by Ricker (1954) and Beverton and Holt (1957). Unlike the Beverton Holt curve, the Ricker curve shows declining recruitment at higher stock sizes. Mortality is considered stock size dependent rather than density dependent. Other models or methods of describing stock-recruitment have been proposed by Deriso (1980), Getz and Swartzman (1981) and Overholtz et al. (1986).

In addition, it is well known that for every salmon population some limits exist that affect growth or survival (Hilborn and Walters 1992). Growth rates often decrease at higher fry densities, and in addition, a reduction in recruits-per-spawner can occur as spawner stock sizes increase. That is, a compensatory relationship exists in which the stock-recruitment curve rises less steeply at higher stock sizes. This relationship provides a guideline for managers to assess that point on the curve for MSY, thus enabling escapement goals to be set accordingly.

Traditionally, managers have relied exclusively on spawner-recruit observations to set escapement goals and frequently use idiosyncratic ideas that have little to do with observed data (Geiger and Koenings 1991). Accurate estimates of escapement are essential to develop spawner-recruit relationships. The need for better salmon spawning escapement estimates and the standardization of estimation procedures has also been well documented (Walters and Ludwig 1981; Pearse 1982; Symons and Waldichuck 1981). Labelle (1994) reported that in British Columbia, deficiencies in Pacific salmon escapement enumeration and resultant stock assessment estimates are well documented. Coho salmon escapement estimates have been described as the most unreliable (Fraser et al. 1982).

Escapements estimated by counting salmon through weirs may also be biased low since only fish observed are enumerated and fish often pass uncounted before or after a weir is operational or through holes in the weir (Van Alen 1996). The weirs in the Alaska Peninsula have been in operation for relatively short periods; only Bear and Nelson Rivers have weir counts for ten years or more. Also, the sockeye salmon escapement to Sapsuk Lake has not been delineated. In some years, perhaps only half of the fish counted at the Nelson River weir spawn in Sapsuk Lake (James

McCullough, ADF&G, personal communication). Fish that pass through the weir are also destined for the Sapsuk River and associated tributaries.

In addition to limited escapement data, sockeye harvest contribution by system is unknown due to the nature of the mixed-stock fisheries in the region and the lack of applied methodology to determine stock specific catches. Although, for Bear Lake we used the spawner-recruit relationship to estimate the escapement level that on average will produce maximum sustained yield of sockeye salmon, it is important to recognize that for the late run return, return per spawner (R/S) data are available for only ten years (1980-1989). A spawner-recruit relationship was developed from 19 years of harvest, escapement and age composition data from Situk River sockeye salmon (Clark et al. 1995). Similarly, for coho salmon stocks returning to the East Alsek-Doame, Akwe, Italio, Situk, Lost, Kaliakh and Tsiu-Tsivt rivers, optimum escapement levels were determined (Clark and Clark 1994). However, in this study it was recommended that spawner-recruit relationships be researched further when 15 years of escapement data and 10 years of total return data were available. Although current Bear River spawner-recruit data indicate large escapements do not result in larger yield, additional years of escapement and harvest data would strengthen the spawner-recruit relationship.

Freshwater production data is often overlooked when developing escapement goals. In southeast Alaska, (Berner's River, Auke Creek, Ford Arm Lake and Hugh Smith Lake) recruit curves were developed for coho stocks using smolt production estimates (Clark et al. 1994). On Kodiak Island, modification of early and late run sockeye escapement levels has been recommended at Karluk Lake following a limnological and fisheries assessment (Schmidt et al. 1996). Thus, by combining habitat data, including the freshwater rearing environment, with spawner-recruit information determining escapement goals may be improved (Geiger and Koenings 1991).

Management of sockeye salmon stocks in Alaska is based on reaching a pre-determined escapement goal. Although active management itself can act as a form of enhancement (Geiger and Koenings 1991), supplementation (stocking of fish into the natural habitat to increase production) may be necessary. Stocking may be used alone or along with other strategies including harvest management (escapement goals), for restoring or enhancing natural production (Cuenco et al. 1993).

The primary goal of a conventional hatchery is to increase adult production for harvest while assuring an adequate brood stock supply (Winton and Hilborn 1994; Steward and Bjornn 1990). Sockeye salmon have been cultured in Alaskan hatcheries for over 100 years (Roppel 1982). In 1977, Russell Creek Hatchery (RCH) was constructed at Cold Bay, primarily as a pink and chum production facility (McNair 1996). However, in the late 1980's, the facility began culture of sockeye and coho salmon, but production of all species ceased in 1992, when the facility closed and was transferred to the Aleutians East Borough. The hatchery was designed to incubate over 200 million salmon eggs. This facility has potential to be reconfigured to incubate and rear sockeye and coho salmon to enhance area production. However, annual operational costs will likely be substantial due to its remote location. At full production, the facility's annual budget was predicted to reach ~$1 million (T. Ellison, ADF&G, personal communication, Anchorage). However, at a production level of 26 million chum and pink salmon, the annual budget was ~$350,000-$400,000 (Clayton Brown, ADF&G retired, personal communication, Anchorage). Prior to closure, the hatchery was configured for culture of ~ 6 million sockeye salmon fry and 1 million coho salmon smolts with a similar operating cost as for pink and chum salmon. Further expansion of sockeye and coho salmon production at RCH would likely increase annual operating expense. However, Pillar Creek Hatchery which is located near the City of Kodiak and is designed to incubate and short term rear ~20 million sockeye has an annual operating budget of ~ $400,000 (C. Clevenger, ADF&G, personal communication, Kodiak).

An alternate method of artificial propagation may be feasible in areas where conventional hatchery enhancement is expensive (Pete Velsco, ADFG, personal communication). The use of large incubation boxes placed in or beside streams has proven successful in Alaska (Roberson and Holder 1987). These boxes, seeded with eggs in the fall, afford protection from disruption (predators) prior to hatching and emergence and provide for volitional migration of fry in the spring. The largest use of instream incubation in Alaska has been at Gulkana where up to 26 million sockeye salmon fry are produced annually (Roberson and Holder 1987). Other streamside incubation locations include Nome, Snake and Solomon Rivers (Nome), 8 Mile Spring (Kaltag), Port Camden Creeks (Kake), Big Boulder Creek, Chilkat Lake Inlet and Klehini River (Haines) and Harding River (Petersburg). Generally, the application of this technique in Alaska is modest and costs as well as production potential are less compared to a conventional hatchery.

The primary role of hatchery or stream-side incubation is to increase the survival rate of the salmon stock in its early life history stage (egg through fry or smolt) relative to its survival rate in natural conditions (Cuenco et al. 1993). In natural conditions egg-to-emergent fry survival for sockeye salmon has averaged 7% (Bradford 1995) with estimates for coho salmon of 2% (Bradford 1995) to 7.7% (Cuenco et al. 1993). In comparison, hatchery survivals often range from 80-90% (Honnold and Clevenger 1995). Likewise, survivals using streamside incubation boxes have been reported as high as 97% for sockeye (Chilkat Lake; S. Reifenstahl, Northern Southeast Regional Aquaculture Association, personal communication, Sitka,) and 83% for coho (Cuenco et al. 1993).

Willie Creek has been suggested as a site for instream incubation boxes largely due to the presence of ground springs (K. Roberson, ADF&G, retired, personal communication, Glennallen). Presently, however, site selection criteria (upwelling water source, sufficient flows and temperature units, etc.) are lacking at this site as well as other streams in the area. It is difficult to find good incubation sites and it is very expensive (~$1,500/hour for helicopter transport) to conduct site selection surveys (P. Velsco, ADF&G, personal communication, Nome).

Other techniques have been used to increase egg-to-fry survivals. At Thumb River, a Karluk Lake tributary stream on Kodiak Island, sockeye eggs were incubated in a remote hatchery, then planted at the eyed stage in stream substrate as a means of rehabilitating a depressed Karluk Lake sockeye stock (White 1986). As result, average egg-to-fry survivals increased from 29% as reported for Karluk natural spawners (Drucker 1970) to 40%. Spawning channels, a technique used commonly in Canada to increase sockeye salmon production, have resulted in similar survivals (INPFC 1984). Egg plants would eliminate the need to rear fry at RCH, however, the technique is laborious and time consuming; on average, ~28,000 eyed eggs can be planted per man-hour.

In addition to incubation, hatchery fish require rearing, feeding and transport to release sites. The use of net pens deployed in lakes to rear sockeye fry, as opposed to hatchery tanks (raceways), can reduce some culture expense (rearing and transport) and still improve survival. Net pen rearing at

Hugh Smith Lake resulted in a 2-fold increase in freshwater survival over free-ranging juveniles (Zadina and Haddix 1990). Net pen rearing has also been employed in Alaska at Klawock Hatchery, English Bay, and also in Washington at Baker Lake, Lake Wenatchee and Redfish Lake (T.Ellison, ADF&G, personal communication, Anchorage). Although the capital expense is reduced (i.e. net pens versus raceways), logistically, remote net pen rearing is costly (personnel, camp, fish food, air charters) and often has an increased risk of disease occurring.

Generally, juvenile-to-adult survival improves as larger hatchery fish are released. However, at a given production level, the larger the fish are cultured (i.e., one million fry compared to one million presmolt or smolt) the more associated costs (C. Clevenger, ADF&G, personal communication, Kodiak). For example, stocking one million presmolts or smolts may cost ~$700,000-$800,000, annually, compared to ~$600,000 to stock 20 million fry (Appendix J). Thus, for each lake stocking project the cost of rearing fish to the desired size at release will have to be compared to the expected production. For lakes with a large capacity for juvenile biomass, fry releases may be more appropriate since rearing would be for a shorter period, and sheer numbers would theoretically provide sufficient adult returns. On Kodiak Island, Spiridon Lake, which is large and rich in zooplankton, has been stocked with sockeye fry since 1990 (~5 million in 1995), providing a large return of adults for harvest (>200,000 in 1994 and 1996). Fry survival has been high (>30% to smolt) when stocked after 6-8 weeks of rearing (L. Malloy, KRAA, personal communication, Kodiak). Shallow lakes with less juvenile capacity, however, may benefit from presmolt or smolt releases to increase juvenile-to-adult survival. At several Kodiak Island lakes with moderate to poor zooplankton biomass levels, sockeye presmolt have been released just before ice-up (late October) to minimize feeding impacts. Adult returns have been good and survival to smolt appears high. In 1996, runs to all Kodiak lakes enhanced with presmolt were larger than pre-season projections. In PWS, Pass and Esther Passage lakes were stocked with presmolt which survived to smolt in excess of 60% (Edmundson et al. 1993). In the case of very shallow lakes with potential for oxygen depletion during winter months, the release of spring smolt after ice-off may be an alternative to presmolt stocking. Currently, few hatcheries rear sockeye salmon to smolt for release. Main Bay Hatchery in Prince Willliam Sound has released net pen reared smolt with reported survival to adult at ~ 20% (Ellison, ADF&G, personal communication). Kitoi Bay Hatchery, located on Afognak Island (Kodiak), cultures sockeye smolt in freshwater raceways, and releases them in a salt water estuary after an imprinting period. At present, returns have been poor and lake releases are being considered to provide a longer imprinting period. Sockeye stocking programs are at risk for problems (Cuenco et al. 1993). Large mortality is possible as result of poor fertilization, mechanical failure, disease, etc., when sockeye eggs are incubated and fry reared in a hatchery. Generally, there is greater potential for stress, health impairment, fish mortality and straying. In addition, when releasing hatchery reared fish into lakes the choice of life stage is important; successful imprinting and increased survival being the primary considerations. The "sensitive" period for olfactory imprinting (SPOI) appears to occur during the smoltification period (Cuenco et al. 1993). The SPOI was evident between three to four weeks after the onset of smoltification in Atlantic salmon (Morin et al. 1989). Stocking of adults or eggs should provide better imprinting compared to stocking fry or smolt; however, would not provide a survival advantage. If insufficient imprinting occurs, adults may stray to adjacent lake or river systems, potentially impacting the genetic integrity of local salmon stocks and decreasing returns to the stocked system. The stocking of large fry, presmolt or smolt should provide increased survivals; however, significant size differences between natural and stocked fish may result in predation or competition for food

(Cuenco et al. 1993). Presmolt or smolt that remain in a lake for an additional year (age-2 at migration), may exacerbate these impacts. If the rearing capacity is overtaxed in sockeye lakes, a predator resistant zooplankton community may form, lowering efficiency of natural smolt production (Kyle et al. 1988). Upon migration from a lake, adverse estuarine conditions may also affect smolt survival (Winton and Hilborn 1994).

Lake fertilization in Alaska (Kyle 1994ab; Kyle et al. 1996) and Canada (LeBrasseur et al. 1978; Stockner 1987) has been a proven method to increase salmon production. Sockeye salmon systems with depressed returns as a result of poor primary production, and secondary production have benefited from nutrient enrichment in conjunction with fry plants. On Kodiak Island, five sockeye systems are currently being fertilized, with four also stocked with fry. Frazer Lake was fertilized from 1988-1992, contributing to large smolt outmigrations (C. Swanton, ADF&G, personal communication, Kodiak), increased smolt size, and increased adult production (Kyle 1994). This strategy has also been employed in southeast Alaska at Deer Lake to enhance coho salmon production (McNair 1996). Of the shallow oligotrophic lakes (Figure 9), Red Cove, Charlie Hansen, Kashega and Unalaska Lakes are nutrient poor (phosphorous deficient), a consideration for use of lake enrichment. However, due to the saline nature of Red Cove Lake, fertilization is not appropriate. Charlie Hansen Lake has a low escapement per surface area (Figure 15) compared to other shallow lakes which may indicate that escapement or spawning habitat rather than nutrients may limit production. Thus, only Kashega and Unalaska Lakes are candidates for enrichment. Unalaska is deeper and is a more typical sockeye lake, hence it may be the best choice of the two. Water residence time is unknown for either lake, and is needed to make any determination for future lake fertilization. In addition, cost versus benefits would need to be considered. The direct cost of lake enrichment (not including evaluation) may exceed $30,000 per lake.

Habitat restoration is another technique used throughout Alaska to enhance salmon populations. Removing or bypassing stream blockages provides for access by salmon to upstream spawning habitat. In southeast Alaska, fish ladders have been installed (Bibb 1987) to enhance sockeye and coho production and, in conjunction with fry stocking provide use of lake rearing area (Edmundson et al. 1991). Kodiak Island sockeye and coho salmon production has been greatly improved by similar projects (Blackett 1987; Willette et al. 1995; Honnold and Edmundson 1993; Edmundson et al. 1994). Removal of barriers at Red Cove, John Nelson, Wosnesenski and other Lakes is a relatively inexpensive way to enhance salmon productivity. However, the saline characteristics of these lakes may limit fry growth and survival (Kyle et al. 1993), preventing large increases in production.

SUMMARY AND CONCLUSIONS

The limnological and fishery data pertinent for assessment of sockeye salmon production and selection of potential enhancement options for the study lakes are summarized in Table 26. Production estimates, limitations and unknown factors for production, potential enhancement strategies, and associated risks are presented in Table 27. Lake descriptions in this summary will be presented in the order of shallow to deep and from the South Peninsula to the North Peninsula and to the Aleutian Islands across an east to west gradient.

Acheredin Lake is extremely shallow and is limited in chlor a, phosphorous, and zooplankton. The average escapement for the system has been 4,070 sockeye salmon; however, based on surface area, the lake is predicted to produce ~51,000 adults. Due to its shallowness, dissolved oxygen (DO) depletion could occur during freeze-up, however, data are unavailable to determine winter DO trends. Although phosphorous deficiency is a criteria for lake enrichment, Archeredin Lake is not a typical (deep) sockeye lake, thus is not considered a good candidate for fertilization. Fry stocking is not recommended, since zooplankton biomass is extremely depressed. Presmolt stocking is also not an option until data are available to assess possible oxygen limitations during the ice-over period. Smolt stocking to provide imprinting to the system prior to outmigration is the only enhancement option until further data are collected (Table 20). If smolt hold over, competition with natural recruitment could occur. Also, if adults stray, they could impact the genetic integrity of other stocks, as well as decrease returns .

Wosnesenski Lake is also a small, shallow system containing a scarcity of zooplankton. Juvenile and adult fishery production data are also sparse but surface area modeling predicts production of ~40,000 adults. Similar to Acheredin Lake, morphometry (shallowness) may limit dissolved oxygen (DO) during the ice-over season. Since these data are unavailable and forage (zooplankton) is limited, stocking (fry and presmolt) is not recommended. Although the lake is moderately phosphorous deficient, it does not meet criteria for lake fertilization. Until further fishery data are collected and assessed, the most effective enhancement option for Wosnesenski Lake is smolt imprinting; however, this could impact resident sockeye juveniles if hatchery smolts hold over. Also, adults may stray to other systems.

Mortensen Lake is extremely small and shallow and also contains few zooplankton. The average sockeye escapement (6,840) is double the predicted production potential (3,300) based on surface area. Little is known about the lake's spawning habitat or the juvenile recruitment. The low zooplankton biomass is not conducive to fry stocking; however, a low level (50,000-100,000) presmolt stocking program may be an option if escapements decline below production potential. However, if fish are not stocked when their metabolism has slowed (just prior to freeze-up) and forage requirements are minimal, they could compete with "wild" fry for limited zooplankton. The stocking of smolt may be more appropriate since the risk of hatchery fish holding over are less than with presmolt. However, smolt may not imprint properly and straying of adults could occur. Because the lake is eutrophic (Figure 9), fertilization is not an enhancement option.

Morzhovoi Lake is also shallow, highly turbid, and has a moderate level of zooplankton. Surface area indicates a production potential of ~68,000 adults which is considerably more than the average escapement of ~19,000. Even if exploitation is 40% (Koenings and Burkett 1987) run size (~32,000) is less than half of potential. The lake's spawning habitat and juvenile production have not been investigated. Fry stocking is not recommended due to zooplankton biomass levels; however, a low level (50,000-100,000) presmolt or smolt stocking program may be an option. Presmolt should be stocked in late fall (October or November) when feeding has declined to avoid competition with "wild" fry. Morzhovoi Lake is quite shallow and because of the potential for low DO, smolt stocking may be more appropriate in the spring. Smolt may not imprint as effectively as presmolt, and could possibly stray more. Because the lake is highly eutrophic (Figure 9), fertilization is not an enhancement option.

Swede Lake is small and shallow and it's production is limited by very low levels of zooplankton. Sockeye salmon escapement has averaged only 590 even though a production of ~25,000 is predicted by the surface area model. Additional data are needed to determine if spawning habitat or juvenile survival limits production. Also, DO profiles are needed to assess any overwinter rearing limitations. Fry stocking is not an enhancement option at this time due to poor forage (zooplankton) as well as the aforementioned data limitations. Also, the current low escapements would make collection of broodstock for presmolt or smolt stocking problematic; to provide for natural spawning less than 50% of the escapement should be used for an eggtake. In addition, it would be risky to stock large sockeye (presmolt or smolt) in a lake with such a limited recruitment; holdover fish could compete and contribute significantly to wild fry mortality. Swede Lake is oligotrophic, but nutrient deficiency (phosphorous) is not serious enough to consider nutrient enrichment.

Thin Point Lake is shallow, eutrophic, and virtually devoid of zooplankton. However, it is large in surface area and results in a predicted return of ~87,500 sockeye salmon. The average escapement (~25,000) is much smaller than predicted production. Additional data are needed to determine if spawning habitat or juvenile survival limits production. Fry stocking is not recommended; however, a low level (50,000-100,000) presmolt or smolt stocking program may be an option to increase production. Presmolt should be stocked when their metabolism has slowed to avoid competition with "wild" fry for forage. The risk of straying and genetic drift (hybridization) should be considered if smolt are stocked. Because the lake is highly eutrophic (Figure 9), fertilization is not an enhancement option.

Big Fish Lake is shallow, eutrophic, and has low zooplankton biomass. Based on it's surface area, potential adult production is predicted at ~62,000. Escapement has been low, averaging only 4,670 sockeye. Juvenile production data are unknown. Due to its shallowness, DO depletion could occur during freeze-up; however, data are unavailable to determine winter DO trends. Fry stocking is not recommended due to the lake's low zooplankton biomass. Presmolt stocking is not an option until data are available to assess possible oxygen limitations during the ice-over period. Smolt stocking to provide imprinting to the system prior to outmigration is the only recommended enhancement option until further data are collected (Table 27). If smolt hold over, competition with natural recruitment could occur. Also, if adults stray they could impact the genetic integrity of other stocks, as well as decrease returns.

Ilnik Lake is shallow, eutrophic, and has low zooplankton biomass. Based on it's surface area, potential adult production is estimated at ~35,000 sockeye, which is considerably less than the estimated average escapement (~52,000). Juvenile fishery production data are unknown. Fry stocking is not recommended due to the lake's low zooplankton biomass, nor is presmolt stocking suggested until data are available to assess possible oxygen limitations during the ice-over period. Smolt stocking to provide imprinting to the system prior to outmigration is the only enhancement option. If smolt hold over, competition with natural recruitment could occur. Also, if adults stray they could impact the genetic integrity of other stocks, as well as decrease returns.

Sandy Lake is shallow, mesotrophic, and has a low zooplankton biomass. This lake has large surface area which predicts a return of ~118,000 sockeye salmon. Escapement has averaged

~55,000 sockeye. Additional data are needed to determine other production limitations, aside from zooplankton, such as spawning habitat, winter DO levels and juvenile survival. Fry stocking is not recommended; however, a low level (50,000-100,000) presmolt or smolt stocking program may be an option to enhance production. Presmolt should be stocked when their metabolism has slowed (late fall) to avoid competition with "wild" fry for forage. The risk of straying and genetic drift should be considered if smolt are stocked. Because the lake is mesotrophic (Figure 9), it is not considered a candidate for fertilization.

Southwest Coast Lake is shallow, eutrophic, and has moderate zooplankton biomass. Escapement has averaged 1,710 sockeye salmon. Based on it's surface area the potential sockeye production is ~ 58,300. Juvenile production data are unknown. Due to its shallowness, DO depletion could occur during freeze-up; however, data are unavailable to determine winter DO trends. Fry stocking is not recommended due to the lake's low zooplankton biomass. Presmolt stocking is not an option until data are available to assess possible oxygen limitations during the ice-over period. Smolt stocking to provide imprinting to the system prior to outmigration is the only enhancement option until further data are collected (Table 27). If smolt hold over, competition with natural recruitment could occur. Also, if adults stray they could impact the genetic integrity of other stocks, as well as decrease returns.

Kashega Lake is extremely shallow and is limited in chlor-a, phosphorous, and zooplankton. Juvenile and adult fishery production data are unknown. Based on surface area, the lake is predicted to produce ~18,000 sockeye or more than double the average escapement of 7,267. Due to its shallowness, DO depletion could occur during freeze-up; however, data are unavailable to determine winter DO trends. Although this oligotrophic lake meets criteria (severe phosphorous deficiency) for lake enrichment, it is not a typical (deep) sockeye lake; thus, it may not respond favorably to fertilization. Shallow lakes often have fast flushing rates (low hydraulic residence time), and are not responsive to fertilization. Thus, hydraulic residence time should be determined for this lake. Fry stocking is not recommended since zooplankton biomass is extremely depressed. Presmolt stocking is also not an option until data are available to assess possible oxygen limitations during the ice-over period. If smolt stocking is employed, holdover and straying impacts should be considered.

Upper Volcano Lake is shallow, mesotrophic, and devoid of zooplankton. Based on it's surface area, the potential sockeye production is predicted at ~9,000. This compares to an average escapement of 2,433 sockeye. Juvenile production data are unknown. Due to its shallowness DO depletion could occur during freeze-up; however, data are unavailable to determine winter DO trends. Fry stocking is not recommended, due to the lake's low zooplankton biomass. Presmolt stocking is also not an option until data are available to assess possible oxygen limitations during the ice-over period. Smolt stocking to provide imprinting to the system prior to outmigration is the only enhancement option until further data are collected (Table 27). If smolt hold over competition with natural recruitment could occur. Also, if adults stray they could impact the genetic integrity of other stocks, as well as decrease returns.

John Nelson Lake is a highly saline (20-36 $^{0}/_{00}$), mesotrophic, and of intermediate depth. Zooplankton are abundant (rank 4); however, most are marine species not commonly preyed on by juvenile sockeye salmon. Based on it's surface area the potential adult sockeye production is estimated to be ~17,600. Other than escapement, which has averaged only 500 sockeye, juvenile and adult fishery production data are largely unknown. Aside from salinity, barriers that often block access to the lake also limit sockeye production. Coho are also likely impacted; however, juveniles are present in the lake, indicating some adults migrate past the barriers. Due to the saline nature of the lake, stocking or fertilization are not recommended. The consistent removal of outlet blockages is the preferred enhancement option at this time.

Orzinski Lake is also mesotrophic, slightly saline (1-2 $^0/_{00}$), and of intermediate depth. The lake's zooplankton community is characterized by marine taxa of moderate biomass. Sockeye salmon production, based on surface area, is estimated at ~33,000. The recent escapements have averaged ~24,000 sockeye. Spawning capacity has not been assessed and juvenile data are limited. However, smolt age samples from 1994 indicated fish held over (age-2 fish), possibly result of large recruitment (over utilization of forage) when a large escapement occurred in 1991 (40,000). When the escapement was lower (25,000) in 1992, resultant smolt (1994) were predominantly age-1 which is more typical with a robust rearing environment. Thus, the escapement goal (20,000) should not be exceeded. Since the lake's zooplankton are largely marine species, it is not considered a good candidate for fry stocking. Presmolt stocking is not recommended but smolt imprinting may be feasible since salinity's are low. Straying and holdover risks should be considered if smolt are stocked. The trophic classification of Orzinski Lake as well as current chlor-a and total phosphorous concentrations do not indicate fertilization is an enhancement option.

Red Cove is a saline (3-22 $^0/_{00}$), oligotrophic lake of intermediate depth. Chlor-a and phosphorous levels are low and zooplankton are in moderate abundance and comprised mainly of marine species. Based on it's surface area, the potential sockeye production is ~21,450. Juvenile and adult fishery production data have not been collected; thus, sockeye production limitations such as escapement and spawning habitat are largely unknown. Barriers often block access to adult salmon in this lake. Due to the saline nature of the lake, fertilization, fry stocking, and presmolt stocking are not recommended. Smolt stocking for imprinting may be feasible (since surface salinity's are low); straying and holdover risks should be considered. The consistent removal of outlet blockages is the preferred enhancement option at this time.

Charlie Hansen Lake is oligotrophic, intermediate in depth, and low in zooplankton biomass. Low levels of chlor-a and phosphorous may limit production. Sockeye salmon escapement has averaged only 1,567. The potential production of ~38,500 sockeye is predicted based on the surface area model. The escapement per surface area is low compared to other lakes, thus, additional data are needed to determine if spawning habitat or escapement limits production rather than nutrients. Juvenile production data are also needed to assess limits to production. Lake fertilization is not recommended until the aforementioned data are collected. Fry stocking is also not suggested as current zooplankton biomass levels are low. Presmolt or smolt stocking (50,000-100,000) may be an option to enhance production. Presmolt should be stocked when their metabolism has slowed (late fall) to avoid competition with "wild" fry for forage. The risk of straying and genetic drift should be considered if smolt are stocked.

Wildman Lake is highly eutrophic, of intermediate depth, and contains a large biomass of zooplankton (Rank 1). Approximately 80% of the zooplankton biomass measured in 1994 were useable for sockeye forage; the remainder comprised of very small zooplankters that are an inefficient food source. Escapement, spawning capacity, and juvenile production data are unavailable. The surface area model predicts a potential production of ~54,450 adults; escapement would result in ~4.8 million spring fry. By comparison, the zooplankton biomass model (applied to useable biomass) estimates that this lake could support an extremely high number of fry (>30 million). However, Wildman Lake's zooplankton is not predator resistant and the lack of refuge (vertical migration due to shallow depth and steep-sided morphometry) and evolution to being preyed upon would substantially lower rearing capacity. Consequently, fry stocking is an option but at an initial conservative level of 2-3 million. This stocking level should be evaluated annually through monitoring of the zooplankton community as well as smolt size prior to continuing or increasing fry plants.

McLees Lake is mesotrophic and has a low chlor-a concentration and moderate zooplankton biomass. Based on it's surface area, the potential sockeye production is predicted at ~22,000. Juvenile and adult fishery production data are limited; however, escapement has averaged 2,690 sockeye. Fry stocking is not recommended at the present level of zooplankton biomass. Presmolt stocking in late fall when metabolism has slowed or smolt stocking to provide imprinting to the system prior to outmigration are the only enhancement options until further data are collected (Table 27). If fish hold over, competition with natural recruitment could occur. Also, if adults stray they could impact the genetic integrity of other stocks, as well as decrease returns. Thus, a low number (50,000-100,000) is recommended for initial stocking. Nutrient levels are not within the criteria for lake enrichment.

Summer Bay Lake is considered oligotrophic (nutrient poor) and other than escapement (average 450), little is known about juvenile and adult fishery production limitations. The lake's estimated potential sockeye production based on surface area is 1,100. Low zooplankton biomass makes it a poor candidate for fry stocking. Presmolt stocking in late fall when metabolism has slowed or smolt stocking to provide imprinting to the system prior to outmigration are the only enhancement options until further data are collected (Table 27). If fish hold over competition with natural recruitment could occur. Also, if adults stray they could impact the genetic integrity of other stocks, as well as decrease returns. Thus, a low number of presmolt (50,000-100,000) is recommended for initial stocking. Although phosphorous and chlor-a are somewhat deficient, levels are not within the criteria for lake enrichment.

Unalaska Lake is also classified as oligotrophic, and is nutrient and zooplankton deficient. Escapement has averaged less than 100 sockeye. Other production limitations (spawning habitat, fry survival) are not known. The lake is very small in terms of surface area and modeling predicts a potential production of ~2,200 sockeye. Low zooplankton biomass makes it a poor candidate for fry stocking. Presmolt stocking in late fall when metabolism has slowed or smolt stocking to provide imprinting to the system prior to outmigration are possible enhancement options. However, juvenile hold over and resultant competition with natural recruitment, as well as straying, are potential risks with these stocking strategies. The lake is severely deficient in phosphorous and chlor-a and is morphometrically a more typical sockeye lake. Thus, if hydraulic residence time (HRT) data is found favorable (not rapidly flushing), the lake could be fertilized. This enhancement option is preferred to stocking since risks are lower.

Lower Volcano is a mesotrophic lake and has an extremely low zooplankton biomass. Fishery data are limited. The surface area model predicts a potential sockeye return of ~16,000 . Since the lake's zooplankton biomass is so severely depressed, fry stocking is not recommended as an enhancement option. Likewise, lake enrichment is not an option due to it's mesotrophic nature. Presmolt or smolt stocking could be considered to increase production if the risk of holdover fish competing with natural recruited juveniles and enhanced returns straying are considered.

Bear Lake is the largest, deepest lake of those assessed for limnological and fishery data. It is rich in zooplankton biomass (Rank 2), and the predominant age (age-2) smolts produced are robust (13.7 g; 112 mm). These smolts are much larger than necessary to maximize marine survival. The production of large smolts and data that indicate spawning habitat is limited suggests that the lake is underutilized as a juvenile sockeye nursery area. In addition, the zooplankton model predicts a potential sockeye return of 2.5 million, which is considerably more than the current production as indicated by the average escapement (433,620) and average late run (~660,000). Thus, supplemental fry stocking would utilize the available rearing area and increase production. The zooplankton biomass model indicates the estimated number of spring fry the lake could support is ~double (60 million) the estimate from the average number of female spawners (30 million). Obviously, stocking of 30 million fry into Bear Lake would be excessive and risky since intraspecific interactions (early and late run recruitment interactions) are unknown. However, a more conservative approach appears feasible; initial stocking of 5-10 million fry with 2-4 million increments every 3 years, contingent upon a favorable zooplankton response. Brood stock used for egg collection should be proportioned evenly among the sub-stocks (early and late run); all spawning populations should be represented to assure specific segments are not selected at the expense of others. Thorough monitoring of the zooplankton biomass as well as fall fry and smolt population estimates and size assessment should be conducted in conjunction with stocking.

Sapsuk Lake is large and deep and has a large zooplankton biomass (Rank 3). The zooplankton model predicts a potential sockeye return of 480,000. Fishery data are limited; however, the average Nelson Lagoon escapement (208,000) has not fully utilized the lake's spawning (adults) or rearing (fry) habitat. Supplemental fry stocking would utilize the available rearing area and increase production to fully utilize the spawning habitat. The zooplankton biomass model indicates the estimated number of spring fry the lake could support at 30 million compared to the estimate from the average number of female spawners of 22 million. Stocking should begin in the range of 2-3 million spring fry with incremental increases of 0.5 million every three years, contingent upon a favorable zooplankton response. Thorough monitoring of the zooplankton biomass as well as fall fry and smolt population estimates and size assessment should be conducted in conjunction with stocking.

During the planning phase of the above enhancement options, careful consideration should be given to fishery management issues as related to increases in production. Likewise, the adult sockeye production provided in Table 27 is an estimate based on the surface area model (Figure 14B). This model is a system's average model and as such variability exists; i.e., the actual adult sockeye production may differ considerably for any individual lake compared to the average.

RECOMMENDATIONS

Of the lakes evaluated, Bear and Sapsuk Lakes have the greatest potential for sockeye salmon production (Table 25). The remaining lakes as a whole are predicted to produce less than 25% as many sockeye salmon (some of these lakes may offer coho salmon production potential).

Our recommended enhancement techniques to increase production at each lake are presented in Table 28. Reconfiguration Russell Creek Hatchery should be explored. A plan should be developed for incubation, rearing, and outstocking of sockeye salmon fry, presmolt and smolt. Cost estimates for hatchery operation, including redesign of modules (if necessary) and plumbing, and annual operations and maintenance should be defined.

If stocking projects are developed, thorough evaluations should be included. If fry are stocked, the following fishery and limnological data will need to be assessed: 1) monthly zooplankton density, biomass, and species size 2) relative abundance (survival), age and size of fall fry and outmigrating smolt (hydroacoustics and trawl surveys or a mark/recapture smolt program), 3) marking of enhanced fry prior to stocking, and delineating enhanced contribution by enumeration of a proportion of marks in smolt, adult escapement and catch (thermal marking of otoliths). Presmolt stocking will require assessment of: 1) smolt survival, age, and condition and proportion of holdovers (spring and summer hydroacoustic and trawl surveys, monthly smolt age and size samples), 2) marking of enhanced presmolt prior to stocking, and delineating enhanced contribution by enumeration of a proportion of marks in smolt, adult escapement and catch. Smolt stocking should be assessed by: 1) marking of enhanced smolt prior to stocking, and delineating enhanced contribution by enumeration of a proportion of marks in adult escapement and catch, 2) determining the relative number of holdovers by conducting fall hydroacoustic and trawl surveys.

Lake fertilization projects will also require pre and post assessment. Prior to initiating lake enrichment, smolt or fry age, and size data should be assessed. Once fertilization begins, lake nutrients, chloro-a, and zooplankton density, biomass, and species size should be assessed every three weeks from May through September.

For all the recommended enhancement projects, including barrier removal, escapements should be monitored each year, preferably by weir enumeration.

Although application of supplementation techniques to enhance these sockeye runs are an option, additional investigation of freshwater life history, early and late run spawner distribution (Bear Lake) and habitat use, and mixed stock harvest assessment should be conducted in advance. Specifically, we recommend fall and spring hydroacoustic/trawl surveys, and qualitative smolt sampling to estimate abundance trends, sizes, and ages of juvenile sockeye salmon. In addition, replication of spawning habitat assessment at Bear and Sapsuk Lakes is warranted and initial assessment is recommended for all systems which routinely enumerate escapement. At Bear Lake, color-coded tagging of adult sockeye at the weir with subsequent surveys to determine early and late run spawning location and timing should be conducted. Lastly, the biological escapement goals should remain at current levels (Table 16) and should not be exceeded; further data are needed prior to adjusting these goals.

Weirs currently in operation at all area systems should continue operation to estimate coho escapement, if feasible. Aerial surveys may be more appropriate for some systems. Also, additional systems may warrant weir installation to improve sockeye salmon escapement estimates. The current catch sampling program should be expanded to enable system-specific harvest to be delineated.

The Alaskan Peninsula Lakes investigations have provided the opportunity to develop new information on shallow lakes that produce sockeye salmon. These types of lakes previously have had very limited investigations. The investigations conducted provide strong evidence of very limited zooplankton communities in many of these lakes. As juvenile sockeye salmon are generally considered to be obligate zooplanktivores, the lack of well developed zooplankton communities suggests that the relatively low production of sockeye salmon per unit surface area observed in these lakes (Figure 14 A) is founded in their basic ecology. However, enhancement projects are designed to overcome natural limitations of lakes, such as limited spawning areas (fry plants), nutrients (lake fertilization), or adult passages (fishways). Since some shallow lakes, such as Black Lake in the Chignik area, have had exceptional sockeye salmon production per unit area, there is a possibility that these limits can be overcome. Since these lake's sockeye populations are believed to be supported by macro-invertebrates from the benthos and littoral areas of the lake, the deep lake model (Koenings and Burkett 1987) which has usually been used to assess sockeye salmon potential may be inappropriate for these types of lakes. An experimental approach of incremental annual increases in stocking these types of lakes with fry reared to different levels of development would help determine if increased production is possible. Monitoring of survival and growth would be essential to evaluate the program. However, prior to beginning such a program, a late winter water quality sample should be taken to determine if sufficient dissolved oxygen exists to allow overwintering. If sampling conditions during late winter preclude obtaining a water quality sample, a spring smolt program to monitor natural smolt abundance and size would also provide a measure of the ability of the lake to overwinter fish and determine if further enhancement is feasible. Most of the shallow lakes are potential candidates for such studies so the selected lake for such experimentation can be based on logistics and local support for funding such a project. Such an approach would be clearly experimental as we have no historical basis for determining the probability of a favorable outcome. The enhancement strategies for the lakes described earlier (Table 27) are based on historical data and should be considered for overall feasibility prior to undergoing experimental studies described here.

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Table 1. Limnological sampling frequency for the 23 Alaska Peninsula study lakes, 1993-1995.

Region/Lake	Year	Fequency	Region/Lake	Year	Frequency
Southcentral			***Northcentral***		
Archeredin	1994	4	Bear	1995	4
	1993	1		1994	4
John Neslon	1994	4		1993	3
Orzinski	1995	3	Big Fish	1994	4
	1994	4		1993	2
	1993	2	Ilnik	1994	4
Red Cove	1994	4		1993	4
	1993	2	Sandy	1995	3
Wosnesenski	1994	4		1994	4
	1993	1		1993	2
			Sapsuk	1995	4
Cold Bay				1994	4
				1993	2
Charlie Hansen	1995	4	Southwest Coast	1994	4
	1994	4	Wildman	1995	3
	1993	2		1994	3
Mortensen	1994	4		1993	2
	1993	2			
Morzhovoi	1995	4	***Unalaska Island***		
	1994	4			
	1993	2	Kashega	1994	3
Swede	1994	4	McLees	1994	4
	1993	2	Summer Bay	1994	4
Thin Point	1995	4	Unalaska	1994	4
	1994	4	Volcano, Lower	1994	3
			Volcano, Upper	1994	3

Table 2. Geographic location and morphometric parameters for the 23 Alaska Peninsula-Aleutian Islands area study lakes.

Lake	Latitude (N)	Longitude (W)	Surface Area (km^2)	Mean Depth (m)	Maximum Depth (m)	Volume ($\times 10^6\ m^3$)
Shallow						
Archeredin	55° 12'	160° 40'	9.2	0.9	1.4	8.6
Big Fish	55° 46'	161° 47'	11.2	1.3	3.0	14.6
Ilnik	56° 34'	159° 41'	6.3	1.0[a]	2.0[a]	9.5 [a]
Kashega	53° 27'	167° 07'	3.2	0.9	2.0	3.0
Mortensen	55° 10'	162° 40'	0.6	0.9	2.1	0.6
Morzhovoi	55° 08'	163° 14'	12.3	1.4	3.0	17.4
Sandy	56° 07'	159° 55'	21.6	2.4	6.7	52.7
Southwest Coast	55° 55'	161° 30'	10.6	1.3	2.0	13.9
Swede	54° 44'	163° 16'	3.9	2.1	4.0	8.1
Thin Point	55° 02'	162° 38'	15.9	1.9	2.4	30.8
Volcano, Upper	53° 48'	167° 03'	1.6	1.3	2.0	2.1
Wosnesenski	55° 13'	161° 22'	7.2	0.9	2.0	6.8
Intermediate						
Charlie Hansen	54° 58'	163° 06'	7.0	4.2	14.6	29.1
John Nelson	55° 13'	160° 32'	3.2	6.9	13.0	22.0
McLees	54° 00'	166° 43'	4.0	6.0	12.0	24.0
Orzinski	55° 44'	160° 05'	6.0	7.8	15.5	46.7
Red Cove	55° 18'	160° 25'	3.9	7.7	16.0	29.9
Summer Bay	53° 53'	166° 24'	0.2	5.8	11.3	1.4
Unalaska	53° 52'	166° 32'	0.4	4.8	9.0	2.1
Volcano, Lower	53° 48'	167° 03'	2.9	6.4	16.5	18.6
Wildman	56° 28'	159° 40'	9.9	5.2	11.5	51.3
Deep						
Bear	56° 00'	160° 15'	25.6	32.3	104.0	826.5
Sapsuk	55° 41'	161° 01'	11.0	40.4	87.0	443.1

[a] Preliminary estimate.

Table 3. Average light extinction coefficient (K_d), euphotic zone depth (EZD), secchi disk (SD) transparency, and euphotic volume (EV) for the 23 Alaskan Peninsula study lakes, 1993-1995.

	K_d (m^{-1})	std.dev.	EZD (m)	std.dev.	SD (m)	std.dev.	EV ($x10^6$ m^3)
Low Attenuation							
Sapsuk	0.152	0.043	32.7	10.2	9.6	4.2	241
Bear	0.243	0.049	19.6	3.7	5.5	1.9	380
Summer Bay	0.246	0.097	21.9 [a]	10.9	3.8	1.3	1
Orzinski	0.279	0.071	16.7 [a]	5.8	3.9	1.0	47
Lower Volcano	0.280	0.060	16.9 [a]	3.4	6.3	0.9	19
Charlie Hansen	0.347	0.142	14.7 [a]	4.8	4.3 [b]	0.7	29
John Nelson	0.352	0.033	13.2 [a]	1.2	3.7	1.2	22
McLees	0.372	0.153	13.8 [a]	4.5	3.6	1.0	16
Moderate Attenuation							
Unalaska	0.416	0.129	11.9 [a]	3.6	4.3	1.8	2
Swede	0.425	0.031	10.8 [a]	0.8	3.0 [b]	0.9	8
Red Cove	0.500	0.066	9.3 [b]	1.3	3.5	0.7	25
Sandy	0.538	0.235	10.0 [b]	4.5	1.5	0.6	53
Wosnesenski	0.550	0.265	10.8 [a]	7.1	1.4 [b]	0.2	7
Kashega	0.575	0.269	9.1 [a]	3.7	2.6 [a]	0.1	3
Archeredin	0.613	0.268	8.8 [a]	4.0	1.4 [b]	0.3	9
Wildman	0.633	0.336	9.3 [b]	5.8	1.9	0.6	48
Upper Volcano	0.694	0.208	7.0 [a]	2.1	2.4 [a]	0.9	2
High Attenuation							
Ilnik	1.253	0.499	4.1 [a]	1.4	1.4	0.5	9
Mortensen	1.382	0.284	3.4 [a]	0.7	1.0 [b]	0.8	4
Thin Point	1.465	0.410	3.3 [a]	0.9	0.6	0.2	31
Morzhovoi	2.375	1.347	2.6 [b]	1.6	0.5	0.3	17
Big Fish	2.430	0.924	2.2 [b]	1.0	0.6	0.5	13
Southwest Coast	2.899	0.609	1.7 [b]	0.4	0.3	0.1	14

[a] indicates value > maximum depth

[b] indicates value > mean depth

Table 4. Mean values for general water chemistry parameters, nutrient concentrations, and algal pigments obtained from the 1-m stratum in the 23 study lakes.

Region/Lake	Sp. Cond. (umhos cm^{-1})	pH (Units)	Alkalinity (mg L^{-1})	Turbidity (NTU)	Color (Pt units)	Calcium (mg L^{-1})	Magnesium (mg L^{-1})	Iron (ug L^{-1})	Total -P (ug L^{-1})	Total filter-able - P (ug L^{-1})	Filterable reactive - P (ug L^{-1})	Total Kjel-dahl - N (ug L^{-1})	Ammonia (ug L^{-1})	Nitrate+ nitrite (ug L^{-1})	Reactive silicon (ug L^{-1})	Carbon (ug L^{-1})	Chloro-phyll *a* (ug L^{-1})	Phaeo-phytin (ug L^{-1})
Southcentral																		
Archeredin	112	6.8	6.7	1.7	5	7.2	1.6	152	5.7	3.2	2.7	93	4.9	57.1	3,623	314	0.76	0.27
John Nelson	25,170	8.0	63.3	0.7	5	228.9	767.5	51	11.9	7.6	5.0	226	10.8	188.5	2,004	354	2.31	0.48
Orzinski	1,460	7.0	12.1	1.2	4	12.3	32.6	32	7.8	2.5	1.6	107	10.4	45.4	1,204	181	1.59	0.68
Red Cove	4,890	7.5	20.9	1.0	5	33.4	57.4	37	7.3	3.0	2.1	159	6.6	71.2	2,828	264	1.66	0.83
Wosnesenski	111	7.1	21.7	4.4	7	3.5	3.5	449	18.0	5.5	4.4	203	3.6	2.8	4,493	565	1.52	0.31
Cold Bay																		
Charlie Hansen	101	7.0	14.4	1.2	3	7.9	1.7	69	6.5	2.5	2.1	65	2.5	2.0	3,846	182	0.67	0.25
Mortensen	84	7.0	15.5	8.7	11	3.8	1.9	544	76.8	14.1	10.0	491	3.9	4.6	7,751	1,571	15.60	4.41
Morzhovoi	169	7.5	22.9	21.2	7	3.9	3.9	831	225.7	14.7	4.2	1,885	3.7	2.7	718	9,918	40.98	4.14
Swede	82	6.5	14.0	1.0	3	4.8	1.9	45	8.5	4.1	2.1	111	2.3	3.6	4,707	215	0.78	0.24
Thin Point	87	6.8	11.2	10.4	4	3.9	1.9	739	39.1	3.4	2.0	248	3.7	2.1	1,385	1,087	5.24	1.57
Northcentral																		
Bear	81	6.7	12.0	1.1	4	8.4	1.8	32	3.7	2.5	1.5	59	3.1	48.8	3,792	108	0.90	0.24
Big Fish	114	7.2	26.2	20.8	7	5.6	3.0	760	105.1	9.2	4.5	1,272	4.9	2.2	2,595	6,464	13.45	1.92
Ilnik	165	7.4	27.2	3.7	5	6.2	3.9	273	79.8	59.0	55.4	200	3.1	4.7	11,159	431	3.64	2.73
Sandy	76	6.4	7.9	4.7	4	7.1	2.1	257	11.7	5.2	4.7	52	6.4	12.1	6,353	157	0.92	0.22
Sapsuk	68	6.8	16.1	0.6	4	6.1	1.5	12	3.3	1.9	1.6	53	2.7	11.4	3,124	99	1.07	0.26
Southwest Coast	139	7.4	36.8	21.1	14	5.9	5.1	565	134.0	10.4	3.7	1,535	5.8	3.2	251	7,539	31.09	4.39
Wildman	86	8.4	29.8	4.8	5	4.9	2.6	201	188.2	124.2	111.9	619	2.5	3.7	1,919	2,039	21.78	0.94
Unalaska Island																		
Kashega	71	6.9	15.0	0.4	4	5.6	0.9	21	5.1	3.4	2.4	70	5.8	4.0	3,302	113	0.49	0.18
McLees	77	6.9	17.2	1.2	5	6.6	1.4	50	11.8	5.2	3.4	101	1.0	4.0	4,650	258	1.68	0.41
Summer Bay	319	7.3	32.0	1.2	4	26.5	2.4	21	7.2	2.9	1.8	101	3.7	4.0	3,722	250	1.78	0.16
Unalaska	75	6.9	17.8	1.1	3	6.8	1.1	55	4.1	2.0	0.8	59	3.1	13.4	3,426	111	0.66	0.17
Volcano, Lower	129	6.9	19.0	0.5	4	8.2	2.1	22	7.4	3.7	2.1	80	1.7	4.0	7,364	118	0.76	0.17
Volcano, Upper	156	7.4	23.0	1.8	3	10.4	1.9	176	15.8	7.2	5.4	108	1.5	4.0	6,840	129	1.24	0.13

Table 5. Dissolved oxygen concentrations (mg L^{-1}) measured in the surface (1 m) and near bottom of the water column during 1994 in spring (June), summer (July-August), and fall (September) for the 23 Alaska Peninsula-Aleutian Islands area study lakes.

	Spring		Summer		Fall	
	Surface	Bottom	Surface	Bottom	Surface	Bottom
Shallow						
Archeredin	13.3	12.6	10.3	7.5	11.7	8.8
Big Fish	14.1	13.5	10.5	6.6	10.6	10.2
Ilnik	13.4	12.2	10.8	8.9	13.3	12.7
Kashega	na [a]	na [a]	10.9	10.1	12.5	11.5
Mortensen	13.8	12.6	10.9	7.3	12.1	10.9
Morzhovoi	14.4	13.3	10.9	9.7	11.7	11.3
Sandy	13.0	11.0	10.9	6.7	11.7	11.4
Southwest	14.4	13.7	9.9	8.3	11.7	10.9
Swedes	14.2	13.0	10.5	9.2	11.5	10.5
Thin Point	13.9	13.2	10.7	8.9	11.7	11.1
Upper Volcano	na [a]	na [a]	10.7	10.5	12.8	12.0
Wosnesenski	12.9	11.6	10.4	9.1	11.0	10.6
Intermediate						
Charlie Hansen	14.9	12.7	11.0	10.5	11.3	10.4
John Nelson	13.8	5.0	10.6	0.4	11.5	0.4
McLees	13.4	13.0	10.6	9.8	11.8	11.1
Orzinski	14.7	15.4	10.7	1.9	11.5	11.1
Red Cove	13.8	0.8	10.2	0.2	10.8	0.2
Summer Bay	13.6	12.8	10.4	8.4	11.0	9.6
Unalaska	13.6	11.0	10.0	9.2	12.1	11.2
Lower Volcano	na [a]	na [a]	10.3	7.2	11.4	10.2
Wildman	13.2	12.4	9.4	8.8	10.2	8.0
Deep						
Bear	15.0	14.3	11.6	10.5	10.9	10.9
Sapsuk	14.9	14.5	11.7	10.3	11.9	10.7

[a] na indicates not available.

Table 6. Comparison of some major dissolved constituents from the freshwater and brackish-saline lakes of the Alaska Peninsula-Aleutian Islands area study lakes.

	Constituent					
Lake	Salinity ($^0/_{00}$)	Conductivity (umhos cm^{-1})	Calcium (mg L^{-1})	Magnesium (mg L^{-1})	Ca:Mg (atom ratio)	Alkalinity (mg L^{-1})
Freshwater Lakes[a]	0	115	7.2	2.3	1.9	19.3
Orzinski (surface)	1	1,460	12.3	32.6	0.2	12.1
Orzinski (bottom)	2	4,726	49.2	149.7	0.2	23.0
Red Cove (surface)	3	4,890	33.4	57.4	0.4	20.9
Red Cove (bottom)	22	29,351	257.7	861.6	0.2	150.7
John Nelson (surface)	20	25,170	228.9	767.5	0.2	63.3
John Nelson (bottom)	36	47,125	424.0	1,362.0	0.2	120.1
Seawater	35	44,700	412.0	1,294.0	0.2	140.0

[a] Mean value for the 20 freshwater Alaska Peninsula study lakes.

Table 7. Mean values for general water chemistry parameters, nutrient concentrations, and algal pigments obtained from the 1-m stratum in the 23 study lakes.

Region/Lake	Sp. Cond. (umhos cm^{-1})	pH (Units)	Alkalinity (mg L^{-1})	Turbidity (NTU)	Color (Pt units)	Calcium (mg L^{-1})	Magnesium (mg L^{-1})	Iron (ug L^{-1})	Total -P (ug L^{-1})	Total filter-able - P (ug L^{-1})	Filterable reactive - P (ug L^{-1})	Total Kjel-dahl - N (ug L^{-1})	Ammonia (ug L^{-1})	Nitrate+ nitrite (ug L^{-1})	Reactive silicon (ug L^{-1})	Carbon (ug L^{-1})	Chloro-phyll *a* (ug L^{-1})	Phaeo-phytin (ug L^{-1})
Southcentral																		
Archeredin	112	6.8	6.7	1.7	5	7.2	1.6	152	5.7	3.2	2.7	93	4.9	57.1	3,623	314	0.76	0.27
John Nelson	25,170	8.0	63.3	0.7	5	228.9	767.5	51	11.9	7.6	5.0	226	10.8	188.5	2,004	354	2.31	0.48
Orzinski	1,460	7.0	12.1	1.2	4	12.3	32.6	32	7.8	2.5	1.6	107	10.4	45.4	1,204	181	1.59	0.68
Red Cove	4,890	7.5	20.9	1.0	5	33.4	57.4	37	7.3	3.0	2.1	159	6.6	71.2	2,828	264	1.66	0.83
Wosnesenski	111	7.1	21.7	4.4	7	3.5	3.5	449	18.0	5.5	4.4	203	3.6	2.8	4,493	565	1.52	0.31
Cold Bay																		
Charlie Hansen	101	7.0	14.4	1.2	3	7.9	1.7	69	6.5	2.5	2.1	65	2.5	2.0	3,846	182	0.67	0.25
Mortensen	84	7.0	15.5	8.7	11	3.8	1.9	544	76.8	14.1	10.0	491	3.9	4.6	7,751	1,571	15.60	4.41
Morzhovoi	169	7.5	22.9	21.2	7	3.9	3.9	831	225.7	14.7	4.2	1,885	3.7	2.7	718	9,918	40.98	4.14
Swede	82	6.5	14.0	1.0	3	4.8	1.9	45	8.5	4.1	2.1	111	2.3	3.6	4,707	215	0.78	0.24
Thin Point	87	6.8	11.2	10.4	4	3.9	1.9	739	39.1	3.4	2.0	248	3.7	2.1	1,385	1,087	5.24	1.57
Northcentral																		
Bear	81	6.7	12.0	1.1	4	8.4	1.8	32	3.7	2.5	1.5	59	3.1	48.8	3,792	108	0.90	0.24
Big Fish	114	7.2	26.2	20.8	7	5.6	3.0	760	105.1	9.2	4.5	1,272	4.9	2.2	2,595	6,464	13.45	1.92
Ilnik	165	7.4	27.2	3.7	5	6.2	3.9	273	79.8	59.0	55.4	200	3.1	4.7	11,159	431	3.64	2.73
Sandy	76	6.4	7.9	4.7	4	7.1	2.1	257	11.7	5.2	4.7	52	6.4	12.1	6,353	157	0.92	0.22
Sapsuk	68	6.8	16.1	0.6	4	6.1	1.5	12	3.3	1.9	1.6	53	2.7	11.4	3,124	99	1.07	0.26
Southwest Coast	139	7.4	36.8	21.1	14	5.9	5.1	565	134.0	10.4	3.7	1,535	5.8	3.2	251	7,539	31.09	4.39
Wildman	86	8.4	29.8	4.8	5	4.9	2.6	201	188.2	124.2	111.9	619	2.5	3.7	1,919	2,039	21.78	0.94
Unalaska Island																		
Kashega	71	6.9	15.0	0.4	4	5.6	0.9	21	5.1	3.4	2.4	70	5.8	4.0	3,302	113	0.49	0.18
McLees	77	6.9	17.2	1.2	5	6.6	1.4	50	11.8	5.2	3.4	101	1.0	4.0	4,650	258	1.68	0.41
Summer Bay	319	7.3	32.0	1.2	4	26.5	2.4	21	7.2	2.9	1.8	101	3.7	4.0	3,722	250	1.78	0.16
Unalaska	75	6.9	17.8	1.1	3	6.8	1.1	55	4.1	2.0	0.8	59	3.1	13.4	3,426	111	0.66	0.17
Volcano, Lower	129	6.9	19.0	0.5	4	8.2	2.1	22	7.4	3.7	2.1	80	1.7	4.0	7,364	118	0.76	0.17
Volcano, Upper	156	7.4	23.0	1.8	3	10.4	1.9	176	15.8	7.2	5.4	108	1.5	4.0	6,840	129	1.24	0.13

Table 8. Total nitrogen to phosphorus ratio by weight (TN:TP) indicating relative nitrogen (N) and phosphorus (P) deficiency in the 23 study lakes.

Severe N Deficiency		*Optimal N:P*		*Moderate P Deficiency*		*Severe P Deficiency*	
Ilnik	5.7	Sandy	12.1	Charlie Hansen	22.8	Orzinski	43.1
Wildman	7.3	Thin Point	14.2	Lower Volcano	25.2	Sapsuk	43.2
		Mortensen	14.3	Wosnesenski	25.3	Archeredin	58.6
		Upper Volcano	15.7	Southwest Coast	25.4	Bear	64.5
		Morzhovoi	18.5	Big Fish	26.8	Red Cove	69.8
		McLees	19.6	Swede	29.8	John Nelson	77.2
				Summer Bay	32.2		
				Kashega	32.2		
				Unalaska	39.1		

Table 9. Mean seasonal abundance and percent composition of the major macrozooplankton taxa collected in the 23 Alaska Peninsula-Aleutian Island study lakes, 1994.

Lake	Taxon	Density (animals m^{-2})	Percent of Total
Freshwater			
Wildman	*Daphnia*	665,005	47
	Bosmina	386,479	27
	Chydorinae	268,689	19
	Cyclops	99,457	7
Bear	*Bosmina*	404,694	60
	Cyclops	264,627	40
Sapsuk	*Cyclops*	357,592	68
	Bosmina	164,992	32
McLees	*Bosmina*	136,970	83
	Cyclops	24,708	15
Southwest Coast	*Cyclops*	81,376	98
	Eurytemora	1996	2
Morzhovoi	*Eurytemora*	32,660	55
	Cyclops	25,762	44
Charlie Hansen	*Bosmina*	41,887	91
	Cyclops	4,035	9
Summer Bay	*Eurytemora*	25,473	93
	Cyclops	1,651	6
Mortensen	*Eurytemora*	15,117	97
Volcano, Lower	*Bosmina*	7,282	49
	Cyclops	7,244	49
Sandy	*Eurytemora*	4,605	64
	Bosmina	1,747	24
	Cyclops	651	9
Big Fish	*Cyclops*	6,258	96
	Bosmina	144	2
Wosnesenski	*Bosmina*	1,590	45
	Eurytemora	1,359	38
	Cyclops	566	16
Swede	*Cyclops*	2,076	65
	Bosmina	857	27
Archeredin	*Cyclops*	1,624	71
	Eurytemora	438	19
Ilnik	*Chydorinae*	438	27
	Daphnia	430	27
	Bosmina	382	24
	Eurytemora	207	13
	Cyclops	136	8
Unalaska	*Eurytemora*	1,083	72
	Bosmina	143	9
	Chydorinae	128	8
	Cyclops	80	5
	Harpacticoida	64	4
Volcano, Upper	*Cyclops*	414	84
	Bosmina	43	9
Kashega	*Bosmina*	96	36
	Cyclops	96	36
	Daphnia	32	12
	Eurytemora	32	12
Thin Point	*Cyclops*	64	44
	Bosmina	32	22
	Harpacticoida	24	17
	Daphnia	16	11
Brackish/Saline			
John Nelson	*Acartia*	133,935	55
	Evadne	108,564	44
	Podon	2,795	1
Orzinski	*Eurytemora*	60,938	99
Red Cove	*Acartia*	52,468	99
	Evadne	319	1

Table 10. Seasonal maximum density (animals m^{-2}) and peak occurrence of the major macrozooplankton taxa in the 23 Alaska Peninsula-Aleutian Islands area study lakes, 1994.

Lake	Taxon	Maximum Density	Peak Occurrence
Freshwater			
Wildman	*Daphnia*	718,152	early September
	Bosmina	719,216	late August
	Chydorinae	761,146	early September
	Cyclops	119,427	late August
Bear	*Bosmina*	563,075	early September
	Cyclops	374,911	late July
Sapsuk	*Cyclops*	589,726	early September
	Bosmina	332,005	early September
McLees	*Bosmina*	353,911	late August
	Cyclops	42,886	late June
Southwest Coast	*Cyclops*	226,057	early June
Morzhovoi	*Eurytemora*	84,714	mid August
	Cyclops	77,707	mid August
Charlie Hansen	*Bosmina*	87,423	early September
	Cyclops	7,856	mid July
Summer Bay	*Eurytemora*	61,996	late September
	Cyclops	4,246	late August
Mortensen	*Eurytemora*	45,435	mid August
Volcano, Lower	*Bosmina*	10,191	late August
	Cyclops	9,767	late August
Sandy	*Eurytemora*	5,732	early June
	Bosmina	2,654	early September
	Cyclops	1,592	early June
Big Fish	*Cyclops*	14,045	early September
Wosnesenski	*Bosmina*	6,263	early September
	Eurytemora	3,025	mid July
	Cyclops	1,911	early September
Swede	*Cyclops*	4,353	early September
	Bosmina	2,124	early September
Archeredin	*Cyclops*	5,032	mid September
	Eurytemora	1,083	mid August
Ilnik	*Chydorinae*	1,147	early September
	Daphnia	1,561	early September
	Bosmina	732	late August
	Eurytemora	318	early September
	Cyclops	191	late August
Unalaska	*Eurytemora*	1,752	early August
	Bosmina	318	early August
	Chydorinae	287	late September
	Cyclops	159	early August
	Harpacticoida	127	late September
Volcano, Upper	*Cyclops*	732	late August
	Bosmina	64	late August
Kashega	*Bosmina*	191	late August
	Cyclops	127	late August
	Daphnia	96	late August
	Eurytemora	96	late September
Thin Point	*Cyclops*	96	mid August
	Bosmina	64	mid August
	Harpacticoida	64	late May
Brackish/Saline			
John Nelson	*Acartia*	176,752	mid September
	Evadne	138,003	early June
	Podon	5,732	early August
Orzinski	*Eurytemora*	50,956	early August
Red Cove	*Acartia*	114,650	mid July

Table 11. Mean seasonal biomass and percent composition of the major macrozooplankton taxa collected in the 23 Alaska Peninsula - Aleutian Islands study lakes, 1994.

Lake	Taxon	Biomass (mg m^{-2})	Percent of Total
Freshwater			
Wildman	*Daphnia*	1793.0	68
	Bosmina	442.0	17
	Cyclops	216.0	8
	Chydorinae	173.0	7
Bear	*Bosmina*	931.0	50
	Cyclops	916.0	50
Sapsuk	*Cyclops*	630.0	67
	Bosmina	314.0	33
Morzhovoi	*Eurytemora*	152.0	79
	Cyclops	39.0	20
Southwest Coast	*Cyclops*	149	94
	Eurytemora	10.0	6
McLees	*Bosmina*	121.0	80
	Cyclops	26.0	17
Summer Bay	*Eurytemora*	93.0	98
	Cyclops	1.3	1
Mortensen	*Eurytemora*	55.0	99
Charlie Hansen	*Bosmina*	36.0	91
	Cyclops	3.5	9
Sandy	*Eurytemora*	13.0	83
	Bosmina	1.7	11
	Cyclops	0.7	4
Volcano, Lower	*Cyclops*	6.0	50
	Bosmina	5.8	48
Big Fish	*Cyclops*	9.0	92
	Bosmina	0.4	4
Wosnesenski	*Bosmina*	3.9	47
	Eurytemora	3.0	36
	Cyclops	1.4	17
Unalaska	*Eurytemora*	3.0	90
	Cyclops	0.1	3
	Bosmina	0.1	3
	Chydorinae	0.1	3
Archeredin	*Cyclops*	0.0	75
	Bosmina	0.0	25
Ilnik	*Daphnia*	0.9	32
	Eurytemora	0.8	28
	Bosmina	0.5	18
	Chydorinae	0.4	14
	Cyclops	0.2	7
Swede	*Cyclops*	1.5	62
	Bosmina	0.7	29
Volcano, Upper	*Cyclops*	0.5	75
	Bosmina	0.1	15
Kashega	*Bosmina*	0.3	42
	Cyclops	0.2	29
	Daphnia	0.1	14
	Eurytemora	0.1	13
Thin Point	*Cyclops*	0.1	41
	Bosmina	0.0	24
	Daphnia	0.0	18
	Harpacticoida	0.0	12
Brackish/Saline			
John Nelson	*Acartia*	269.0	55
	Evadne	208.0	43
	Podon	10.0	2
Orzinski	*Eurytemora*	189.0	99
Red Cove	*Acartia*	92.0	98
	Eurytemora	1.0	1
	Evadne	1.0	1

Table 12. Juvenile sockeye and coho salmon weight and length, 1994.

Lake	Species	Sample Date	Sample Size (n)	Average Weight (g)	Average Length (mm)	Condition[a] (K)
Orzinski	sockeye	Jun 6-11	25	8.7	94	1.05
John Nelson	sockeye	May 20	30	0.4	35	0.88
	coho	Sep 17	18	3.9	67	1.33
Thin Point	sockeye	May 24	25	0.2	30	0.78
	coho	Aug 31	24	11.9	97	1.30
Morzhovoi	sockeye	May 25	25	0.2	30	0.81
	coho	Aug 30	16	4.1	65	1.47
Sapsuk	sockeye	May 28	20	0.2	32	0.69

[a] $K=(W/L^3)10^5$

Table 13. Stomach contents of juvenile sockeye and coho salmon taken from Orzinski, John Nelson, Thin Point, Morzhovoi, and Sapsuk Lakes, 1994.

Lake	Species	Sample Date	Sample Size (n)	Total No. Prey Items (#)	Number of Different Taxa (#)	Most Frequent Taxa Found	Common Names	Stomachs Containing Taxa (#)	Total No. of Individuals Found (#)
Orzinski	sockeye	Jun 6-11	25	180	5	*Nematoda* [a]	round worm	12	113
						Gammaridae [b]	scuds, sideswimmers	7	20
						Corophiidae [b]	scuds, sideswimmers	1	25
John Nelson	sockeye	May 20	30	1888	21	*Harpactidida* [c]	copepod	16	50
						Tisbidae [c]	copepod	14	1143
						Gammaridae [b]	scuds, sideswimmers	13	37
	coho	Sep 17	18	392	21	*Gammaridae* [b]	scuds, sideswimmers	11	107
						Amphipoda [b]	scuds, sideswimmers	7	56
Thin Point	sockeye	May 24	25	42	11	*Harpaticoida* [c]	copepod	4	9
						Neomysis mercedes [d]	opossum shrimp	4	6
						Collembola	springtail	4	6
						Diptera larva [f]	fly larva	4	6
	coho	Aug 31	24	747	9	*Neomysis mercedes* [d]	opossum shrimp	17	286
						Nematoda [a]	round worm	14	444
Morzhovoi	sockeye	May 25	25	598	13	*Harpaticoida* [c]	copepod	18	125
						Diptera larva [f]	fly larva	13	20
						Eurytemora [g]	copepod	8	361
	coho	Aug 30	16	529	18	*Chironomidae* [h]	midge larva	16	340
						Diptera larva [f]	fly larva	6	137
Sapsuk	sockeye	May 28	20	129	6	*Cyclopoida* [i]	copepod	11	60
						Cyclopoida nauplii [j]	copepod	10	51
						Bosminidae [k]	water-flea	11	31

-Footnotes continued on next page-

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Notes from John Edmundson, ADF&G, Limnology, Soldotna, 13 August 1996:

[a] Nematoda; the phyllum containing the group of unsegmented worm-like animals. They occur in large numbers in soil, freshwater, and the sea bed.

[b] Gammaridae and Corophiidae are families of the order Amphipoda of the class Malacostraca of the phylum Crustacea, they are mainly free-living marine crustaceans with some freshwater species.

[c] Harpactididae and Tisbidae are families of the order Harpacticoida of the class Copepoda of the phylum Crustacea, mainly marine crustaceans but are universally distributed in freshwater lakes.

[d] Neomysis mercedes is a species of the order Mysidacea of the class Malacostraca of the phylum Crustacea. They are mostly marine but N. mercedes has adapted to freshwater. They resemble miniature shrimp and can grow up to 15 millimeters in length.

[e] Collembola is an insect order of the subclass Apterygota. These are small, primitive, wingless insects.

[f] Diptera is one of the largest and most diverse order of insects. Most Dipterous larvae live in aquatic habitats including streams and lakes and in brackish environments.

[g] Eurytemora; genus of the family Temoridae of the order Calanoida of the Class Copepoda of the phylum Crustacea. Mainly marine crustaceans, Eurytemora includes marine, coastal brackish, fresh-water, or euryhaline species.

[h] Chironomidai; family of the order Diptera. Commonly referred to as midges found in most types of water bodies, including intertidal rockpools and coral reefs; moist soil; phytoelmata; dung.

[i] Cyclopoida; order of the class Copepoda of the phylum Crustacea, including many marine planktonic and bottom dwelling forms as well as freshwater representatives.

[j] Nauplius; the small, compact, active larvae hatched from a copepod egg. After a succession of molts the nauplii developes into an adult copepod.

[k] Bosminidae; family of the order Cladocera of the class Branchiopoda of the phylum Crustacea. Cladocerans are small, transparent, primarily freshwater crustaceans. Reproduction occurrs without fertilization.

Table 14. Orzinski, Sandy, and Sapsuk Lake mean sockeye salmon smolt age and size, 1994-1995.

Year	Sample (n)	Freshwater		Weight (g)	Length (mm)	Condition coefficient (K)
		Age Class	% of Sample			
Orzinski Lake						
1994[a]	5	0	1.9	1.5	58.4	0.75
	5	1	1.9	7.9	88.8	1.13
	249	2	96.1	8.0	95.6	0.92
1995[b]	191	1	96.4	6.7	86.9	1.02
	7	2	3.5	9.6	98.6	1.00
Sandy Lake						
1995[b]	163	1	100	11.0	102.7	1.02
	0	2	0			
Sapsuk Lake						
1995	68	1	90.6	4.3	79.5	0.86
	7	2	9.3	6.5	93.7	0.79

[a] Nelson, P. and Murphy, R. 1995b.

[b] Nelson, P. and Murphy, R. 1996.

Table 15. Bear Lake mean sockeye salmon smolt age and size, 1967-1995.

Year[a]	Sample (n)	Freshwater Age Class	Freshwater % of Sample	Weight (g)	Length (mm)	Condition Coefficient (K)
1967	0	0	0	*na* [b]	*na* [b]	*na* [b]
	10	1	6.1	5.6	84	0.94
	154	2	93.3	11.3	103	1.03
	1	3	0.6	10.2	100	1.02
1968	1	0	0.2	1.3	50.0	1.04
	150	1	24.0	10.6	90.3	1.44
	475	2	75.9	14.6	109.3	1.12
1969	62	1	12.2	10.6	100.5	1.04
	446	2	87.8	11.9	105.5	1.01
1970	47	1	7.8	8.4	91.1	1.11
	555	2	92.2	13.2	108.1	1.04
1971	94	1	27.2	9.4	92.2	1.20
	249	2	72.0	15.1	108.7	1.18
	3	3	0.9	19.3	121.3	1.08
1972 [c]	16	1	9.5	7.1	88.7	1.02
	152	2	90.5	8.2	91.6	1.07
1973	6	1	15.4	9.4	99.7	0.95
	33	2	84.6	12.9	113.3	0.89
1974	23	1	29.9	12.2	112.5	0.86
	54	2	70.1	13.4	114.3	0.90
1975	26	1	22.8	11.6	113.9	0.79
	88	2	77.2	15.9	125.1	0.81
1978	24	1	30.0	7.6	103.0	0.70
	56	2	70.0	10.0	115.3	0.65
1980	2	0	1.4	1.4	54	0.89
	14	1	10.1	2.9	71.1	0.81
	120	2	87.0	7.1	91.9	0.91
	2	3	1.4	17.4	120	1.01
1986 [c]	4	0	0.4	1.4	51.3	1.04
	19	1	2.0	6.4	85.1	1.04
	963	2	95.0	9.1	96.9	1.00
	27	3	3.0	11.1	104.8	0.96

-Continued-

Table 15. (page 2 of 2)

Year[a]	Sample (n)	Freshwater Age Class	Freshwater % of Sample	Weight (g)	Length (mm)	Condition Coefficient (K)
1987	5	1	1.3	11.1	103.0	1.02
	376	2	95.7	12.8	107.9	1.02
	12	3	3.1	16.3	116.2	1.04
1988	11	0	0.5	3.2	66.9	1.07
	1078	1	52.4	10.9	100.6	1.07
	963	2	46.8	17.2	119.5	1.01
	4	3	0.2	22.1	129.3	1.02
1989[d]	12	0	0.8	3.5	63.6	1.36
	409	1	26.2	10.2	98.6	1.06
	1555	2	72.9	14	114.1	0.94
	2	3	0.1	13.8	109.1	1.06
1992	151	1	11.2	7.6	91.7	0.99
	1183	2	88.5	9.2	98.3	0.97
	2	3	0.1	13.1	147.5	0.41
1993[e]	121	1	7.6	7.2	90.2	0.98
	1464	2	92.3	9.1	98.2	0.98
	1	3	0.1	14.1	118.0	0.86
1994[f]	125	1	9.7	9.5	98.7	0.99
	1114	2	87.3	12.0	107.5	0.97
	38	3	3.0	13.8	113.3	0.95
1995[g]	1	0	0.0	3.9	83.0	0.68
	123	1	12.0	11.5	105.1	0.99
	895	2	87.7	13.7	112.3	0.97
	1	3	0.0	21.3	135.0	0.87

[a] Uncited data taken from unpublished ADF&G data.

[b] Data not available.

[c] McCullough, J. 1988.

[d] McCullough, J. 1990.

[e] Nelson, P. and Murphy, R. 1995a.

[f] Nelson, P. and Murphy, R. 1995b.

[g] Nelson, P. and Murphy, R. 1996.

Table 16. Alaska Peninsula sockeye salmon weir counts, estimated total, and peak escapements, 1986-1995.

Region/ Lakes	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Average 1986-1995	Average Weir Counts	Escapement Goals
Southcentral													
Orzinski[a]	10,300	22,800	20,500	15,000	15,000	40,000	25,000	24,717	38,000	30,000	24,132	28,786	20,000
John Nelson[b]	0	100	0	200	400	1,500	900	300	1,100	500	500		
Acheredin[b]	6,800	1,900	3,100	7,100	5,500	3,300	800	1,200	7,100	3,900	4,070		
Cold Bay													
Mortensen[a]	1,400	6,400	4,600	4,800	3,800	14,100	11,400	8,000	5,600	8,300	6,840		3,200-6,400
Thin Point[a]	12,400	10,400	29,600	27,000	19,200	40,600	37,600	18,000	19,450	31,740	24,599	25,595	14,000-28,000
Morzhovoi (Middle Lagoon)[a]	5,500	14,000	11,400	16,000	28,200	14,200	11,000	27,400	20,600	40,700	18,900		16,400-32,800
Charlie Hansen[a]	100	50	200	600	1,260	4,600	6,400	460	1,000	1,000	1,567		400-800
Swedes[a]	400	800	400	300	2,000	440	800	360	100	300	590		600-1200
Northcentral													
Ilnik[a]	66,800	18,125	23,500	15,000	30,000	135,000	45,000	70,000	75,300	39,000	51,773	72,860	40,000-60,000
Wildman (Ocean)[a]	7,200	7500[c]	7700[c]	200	9,200	99,000	14,000	nd	nd	nd	25,920		
Willie Creek[a]	15,500	7,938	4,750	4,125	10,125	29,250	13,313	12,000	nd	nd	12,125		
Sandy[a]	6,900	11,125	43,125	45,000	21,875	94,000	26,500	57,875	115,000	125,000	54,640	120,000	40,000-60,000
Nelson (Sapsuk)	117,000	155,700	142,500	135,000	240,700	268,400	162,300	207,200	325,300	329,400	208,350	208,350	100,000-150,000
Southwest (Coast)[b]	0	1,100	1,500	3,000	3,500	1,200	4,000	1,000	400	1,400	1,710		
Big Fish[b]	2,000	4,400	5,500	1,400	14,500	2,800	6,000	2,500	4,800	2,800	4,670		
Unalaska Island													
Summer Bay[b]	nd	1,000	800	nd	0	nd	0	nd	nd	nd	450		
Unalaska[b]	0	400	0	nd	0	0	0	0	226	255	98		
McLees[b]	1,900	1,500	nd	nd	2,500	nd	6,000	nd	nd	1,550	2,690		
Volcano[b]	300	3,100	700	nd	nd	nd	2,000	nd	4,500	4,000	2,433		
Kashega[b]	4,400	3,000	11,600	nd	16,800	nd	nd	nd	4,400	3,400	7,267		

nd = no data.

Shaded areas are weir escapement counts plus aerial surveys counts conducted after removal of the weir.

[a] Estimated total escapement was used where weir counts were non-existent; where an estimated total escapement was non-existent; then an indexed total escapement was used.

[b] Peak escapement estimates used.

[c] Counts are from years that Ocean River drained directly into the Bering Sea. When Ocean River drains into Ilnik Lake, escapement counts are included in the Ilnik weir counts.

Escapement data are not available for Red Cove, and Wosnesenski systems; escapement goals are not available for John Nelson, Acheredin, Wildman, Willie Creek, Southwest, Big Fish, and Unalaska Island Lakes.

Citations: ADF&G, Alaska Peninsula Annual Salmon Management Reports, 1986-95. Arnold Shaul, personal communication, 1996.

Table 17. Sockeye salmon annual escapement, late run return, and return per spawner, Bear Lake, 1980-1995.

Year	Escapement				Late Run	
	Total[a]	Early Run	Late Run		Total Return	Return/Spawner
1980	675,000	436,962	238,038		545,500	2.29
1981	690,000	475,272	214,728		318,386	1.48
1982	300,000	195,497	104,503		280,870	2.69
1983	330,000	157,857	172,143		319,246	1.85
1984	395,000	286,849	108,151		503,626	4.66
1985	436,212	265,473	170,739		939,836	5.50
1986	273,400	174,479	98,921		870,243	8.80
1987	252,400	169,005	83,395		1,088,611	13.05
1988	310,100	169,440	140,660		690,272	4.91
1989	451,000	246,196	204,804		1,068,712	5.22
1990	546,800	283,854	262,946		922,124	
1991	606,000	432,087	173,913		56,709	
1992	450,000	254,170	195,830		247	
1993	452,000	254,012	197,988			
1994	465,000	260,559	204,441			
1995	305,000	197,039	107,961			
Avg. 1980-95	433,620	266,172	167,448	Avg. 1980-89	662,530	5.05
Avg. 1985-95	413,447			Avg. 1985-89	931,535	7.50

[a] Counts include an estimated escapement after tower and weir counts are stopped.

Tower escapement counts are from 1980-1985, and weir counts (shaded) were started in 1985. The early and late runs have been separated for determining a total return per spawner (escapement) ratio on the late run component only.

Source: ADF&G, Alaska Peninsula-Aleutian Islands Annual Salmon Management Reports, 1985-95; Nelson and Murphy, 1996.

Table 18. Estimated age composition of sockeye escapements into Orzinski Lake, 1990-1995.

Year	Sample[a] Size		Age 1.1	0.3	1.2	2.1	0.4	1.3	2.2	1.4	2.3	3.1	3.2	3.3	2.4	Other[b]	Total
1990	247	Percent	0.0	0.0	48.4	2.8	0.0	12.5	21.0	0.4	14.1	0.0	0.0	0.4	0.0	0.4	100
		Number	0	0	7,258	423	0	1,875	3,145	60	2,117	0	0	60	0	60	14,998
1991	601	Percent	0.0	0.5	29.5	1.0	0.0	38.8	27.4	0.0	2.8	0.0	0.0	0.0	0.0	0.0	100
		Number	0	192	11,718	378	0	15,382	10,862	0	1,128	0	0	0	0	0	39,660
1992	1,041	Percent	0.1	0.0	22.1	2.0	0.0	18.6	21.5	0.7	32.3	0.0	2.0	0.4	0.3	0.0	100
		Number	16	0	5,514	505	0	4,656	5,372	174	8,085	0	494	104	80	0	25,000
1993	1,096	Percent	5.5	0.1	2.5	18.4	0.0	6.5	12.9	0.1	51.4	1.0	0.6	0.9	0.1	0.0	100
		Number	1,366	27	616	4,536	0	1,605	3,189	26	12,714	256	139	218	26	0	24,718
1994	833	Percent	1.1	0.0	75.5	4.0	0.0	4.7	9.9	0.5	3.3	0.0	0.9	0.1	0.0	0.0	100
		Number	410	0	28,685	1,538	0	1,803	3,762	180	1,249	0	338	33	0	0	37,998
1995	635	Percent	22.2	0.0	6.5	6.8	0.0	45.5	14.2	0.1	4.8	0.0	0.0	0.0	0.0	0.0	100
		Number	6,649	0	1,940	2,039	0	13,639	4,263	29	1,443	0	0	0	0	0	30,002
Average	**742**	**Percent**	**4.9**	**0.1**	**32.3**	**5.5**	**0.0**	**22.6**	**17.7**	**0.3**	**15.5**	**0.1**	**0.6**	**0.2**	**0.1**	**0.0**	**100.0**
		Number	**1,407**	**37**	**9,289**	**1,570**	**0**	**6,493**	**5,099**	**78**	**4,456**	**43**	**162**	**69**	**18**	**10**	**28,729**

[a]Samples collected in a fish weir trap.

[b]Other ages include: 1.1, 0.2, 0.4, 3.1

Source:
Alaska Peninsula and Aleutian Islands Management Area Commercial Salmon Catch and Escapement Statistics, Technical Fishery Report Series, 1990-1992.
Alaska Peninsula Management Area Salmon Escapement and Catch Sampling Results, Regional Information Report Series, 1993-1995.

Table 19. Estimated age composition of sockeye escapements into Thin Point Cove, 1989, 1993, and 1995.

Year	Sample[a] Size		Age 0.2	1.1	0.3	1.2	2.1	0.4	1.3	2.2	3.1	1.4	2.3	3.2	3.3	Other[b]	Total
1989	357	Percent	0.0	0.0	0.0	42.1	0.0	0.0	49.0	2.5	0.1	0.6	3.7	0.0	0.0	1.9	100
		Number	0	0	0	15,778	0	0	18,349	935	36	234	1,403	0	0	701	37,436
1993	873	Percent	0.9	0.5	4.2	9.3	8.8	0.0	10.1	26.2	0.2	0.1	39.1	0.3	0.2	0.0	100
		Number	199	108	959	2,111	2,000	0	2,281	5,922	36	18	8,841	72	54	0	22,601
1995	169	Percent	0.0	0.1	0.3	17.6	0.0	0.0	81.5	0.0	0.0	0.0	0.4	0.0	0.0	0.0	100
		Number	0	43	86	5,602	0	0	25,881	0	0	0	129	0	0	0	31,741
Average	**466**	**Percent**	**0.2**	**0.2**	**1.1**	**25.6**	**2.2**	**0.0**	**50.7**	**7.5**	**0.1**	**0.3**	**11.3**	**0.1**	**0.1**	**0.8**	**100.0**
		Number	**66**	**50**	**348**	**7,830**	**667**	**0**	**15,504**	**2,286**	**24**	**84**	**3,458**	**24**	**18**	**234**	**30,593**

[a]Samples collected from subsistence gillnet, 1989 and 1993; samples collected in a fish weir trap, 1995.

[b]Other ages include: 1.1, 0.2, 0.4, 3.1

Source:

Alaska Peninsula and Aleutian Islands Management Area Commercial Salmon Catch and Escapement Statistics, Technical Fishery Report Series, 1989.

Alaska Peninsula Management Area Salmon Escapement and Catch Sampling Results, Regional Information Report Series, 1993 and 1995.

Table 20. Estimated age composition of sockeye escapements into Middle Lagoon, 1995.

Year	Sample[a] Size		Age 0.2	1.1	0.3	1.2	2.1	0.4	1.3	2.2	1.4	2.3	3.2	2.4	Total
1995	69	Percent	0.0	0.0	7.2	55.1	0.0	0.0	34.8	2.9	0.0	0.0	0.0	0.0	100
		Number	0	0	2,949	22,414	0	0	14,157	1,180	0	0	0	0	40,700

[a]Samples collected in a fish weir trap.

Source:
Alaska Peninsula Management Area Salmon Escapement and Catch Sampling Results, Regional Information Report Series, 1995.

Table 21. Estimated age composition of sockeye escapements into Ilnik Lagoon, 1989-1995.

Year	Sample[a] Size		Age 0.2	0.3	1.2	1.1	2.1	0.4	1.3	2.2	1.4	2.3	2.4	Other[b]	Total
1989	373	Percent	0.0	3.2	3.8	0.0	0.0	0.0	73.3	2.5	3.8	7.6	0.0	5.7	100
		Number	0	613	736	0	0	0	14,172	491	736	1,472	0	1,104	19,324
1990	245	Percent	0.0	7.8	50.6	0.0	0.0	0.0	23.7	6.1	5.3	5.7	0.0	0.8	100
		Number	0	2,769	18,069	0	0	0	8,451	2,186	1,894	2,040	0	291	35,700
1991	839	Percent	0.0	5.1	0.8	0.0	0.2	0.0	90.8	0.1	0.2	2.3	0.0	0.5	100
		Number	0	6,894	1,054	0	311	0	122,572	108	316	3,122	0	622	134,999
1992	965	Percent	1.9	14.3	16.6	0.1	0.0	4.7	29.9	3.4	26.9	2.1	0.2	0.0	100
		Number	862	6,430	7,465	28	0	2,126	13,455	1,532	12,098	933	73	0	45,002
1993	923	Percent	0.0	6.6	1.7	0.1	0.0	0.7	37.9	1.4	5.8	44.5	1.3	0.0	100
		Number	0	4,616	1,221	55	0	508	26,526	975	4,043	31,141	914	0	69,999
1994	60	Percent	0.0	35.0	8.3	0.0	0.0	1.7	31.6	0.0	11.7	3.3	8.3	0.0	100
		Number	0	999	238	0	0	48	903	0	333	95	238	0	2,854
1995	365	Percent	2.2	12.5	12.9	0.0	0.0	1.5	65.0	1.0	1.2	3.7	0.0	0.0	100
		Number	866	4,886	5,038	0	0	570	25,344	381	467	1,447	0	0	38,999
Average	**539**	**Percent**	**0.5**	**7.8**	**9.8**	**0.0**	**0.1**	**0.9**	**61.0**	**1.6**	**5.7**	**11.6**	**0.4**	**0.6**	**100.0**
		Number	**247**	**3,887**	**4,832**	**12**	**44**	**465**	**30,203**	**810**	**2,841**	**5,750**	**175**	**288**	**49,554**

[a]Samples collected in a lake beach seine set or commercial set gillnet catch, 1989-1990 and a fish weir trap, 1991-1995.
[b]Other ages include: 1.1, 0.2, 0.4, 3.1

Source:
Alaska Peninsula and Aleutian Islands Management Area Commercial Salmon Catch and Escapement Statistics, Technical Fishery Report Series, 1989-1992.
Alaska Peninsula Management Area Salmon Escapement and Catch Sampling Results, Regional Information Report Series, 1993-1995.

Table 22. Estimated age composition of sockeye escapements into Sandy River, 1989,1994-1995.

Year	Sample[a] Size		Age										Total
			0.2	1.1	0.3	1.2	2.1	1.3	2.2	1.4	2.3	Other[b]	
1989	489	Percent	0.0	0.0	0.2	21.3	0.8	71.3	1.3	0.0	4.4	0.6	100
		Number	0	0	94	9,603	377	32,103	565	0	1,977	282	45,001
1994	1,042	Percent	0.1	1.7	0.1	89.9	0.2	6.0	1.9	0.1	0.1	0.0	100
		Number	153	1,983	75	103,336	200	6,896	2,159	60	139	0	115,001
1995	1,185	Percent	0.6	3.3	0.0	32.0	0.0	60.3	3.0	0.0	0.7	0.0	100
		Number	794	4,131	58	40,013	0	75,390	3,691	0	924	0	125,001
Average:	**905**	**Percent**	**0.3**	**2.1**	**0.1**	**53.7**	**0.2**	**40.1**	**2.3**	**0.0**	**1.1**	**0.1**	**100.0**
		Number	**316**	**2,038**	**76**	**50,984**	**192**	**38,130**	**2,138**	**20**	**1,013**	**94**	**95,001**

[a]Samples collected in a lake beach seine set, 1989 and a fish weir trap, 1994-1995.

[b]Other ages include: 1.1, 0.2, 0.4, 3.1, 3.2, 3.3

Source:

Alaska Peninsula and Aleutian Islands Management Area Commercial Salmon Catch and Escapement Statistics, Technical Fishery Report Series, 1989.

Alaska Peninsula Management Area Salmon Escapement and Catch Sampling Results, Regional Information Report Series, 1994-1995.

Table 23. Estimated age composition of sockeye escapements into Bear River, 1986-1995.

Year	Sample[a] Size		Age 0.2	1.1	0.3	1.2	2.1	0.4	1.3	2.2	3.1	1.4	2.3	3.2	2.4	3.3	Other[b]	Total
1986	1,854	Percent	0.0	0.0	0.0	3.5	1.2	0.0	4.6	58.2	0.0	0.0	32.3	0.0	0.2	0.0	0.0	100
		Number	0	0	99	9,529	3,252	0	12,638	159,100	0	0	88,301	0	458	0	0	273,377
1987	2,075	Percent	0.0	0.0	0.0	2.7	0.1	0.0	14.2	51.3	0.0	0.1	31.2	0.0	0.4	0.0	0.0	100
		Number	0	0	0	6,802	313	0	35,901	129,243	0	152	78,763	0	904	0	0	252,078
1988		Percent	0.0	0.0	0.0	0.4	9.3	0.0	4.8	40.6	0.0	0.0	44.8	0.0	0.1	0.0	0.0	100
		Number	0	100	0	1,100	28,700	0	14,900	126,000	0	100	138,900	100	200	0	0	310,100
1989	2,643	Percent	0.0	0.0	0.0	3.1	8.3	0.0	0.3	58.9	0.0	0.6	27.3	0.0	1.1	0.0	0.4	100
		Number	0	0	0	13,988	37,568	0	1,274	265,796	0	2,752	123,174	0	4,756	0	1,693	451,001
1990	1,515	Percent	0.0	0.0	0.0	12.2	1.0	0.0	2.6	58.9	0.0	0.0	21.0	3.9	0.2	0.1	0.1	100
		Number	0	0	0	66,468	5,508	0	14,322	322,058	0	0	114,942	21,299	1,102	367	734	546,800
1991	2,391	Percent	0.0	0.0	0.0	6.1	7.1	0.0	18.4	60.5	0.0	0.3	6.7	0.1	0.2	0.0	0.6	100
		Number	0	0	106	37,050	43,034	0	111,755	366,361	0	1,624	40,887	353	933	10	3,888	606,001
1992	2,287	Percent	0.0	0.9	0.0	2.1	12.6	0.0	1.9	64.6	0.2	0.7	16.4	0.3	0.1	0.0	0.0	100
		Number	219	4,142	191	9,507	56,879	0	8,436	290,572	990	3,210	73,657	1,555	641	0	0	449,999
1993	2,568	Percent	0.0	0.0	0.0	1.8	11.1	0.0	2.2	37.1	0.0	0.2	45.1	2.2	0.3	0.1	0.0	100
		Number	0	0	0	8,071	50,231	0	9,958	167,321	199	889	203,439	10,157	1,186	550	0	451,451
1994	2,547	Percent	0.0	0.5	0.0	0.7	5.7	0.0	4.0	63.0	0.0	0.1	24.7	0.0	1.1	0.0	0.0	100
		Number	0	2,522	0	3,204	26,698	0	18,703	293,061	0	557	114,888	0	5,204	160	0	464,837
1995	2,416	Percent	0.0	0.1	0.0	2.1	12.2	0.0	0.6	48.8	0.0	0.5	35.0	0.0	0.7	0.0	0.0	100
		Number	0	170	0	6,538	37,204	0	1,817	148,865	0	1,384	106,882	0	2,138	0	0	304,998
Average:	**2,030**	**Percent**	**0.0**	**0.2**	**0.0**	**3.9**	**7.0**	**0.0**	**5.6**	**55.2**	**0.0**	**0.3**	**26.4**	**0.8**	**0.4**	**0.0**	**0.2**	**100.0**
		Number	**22**	**693**	**40**	**16,226**	**28,939**	**0**	**22,970**	**226,838**	**119**	**1,067**	**108,383**	**3,346**	**1,752**	**109**	**632**	**411,064**

[a]Samples collected in a fish weir trap.

[b]Other ages include: 1.1, 0.2, 0.4, 3.1

Source:
Alaska Peninsula and Aleutian Islands Areas Annual Salmon and Herring Management Report, 1988.
Alaska Peninsula and Aleutian Islands Management Area Commercial Salmon Catch and Escapement Statistics, Technical Fishery Report Series, 1989-1992.
Alaska Peninsula Management Area Salmon Escapement and Catch Sampling Results, Regional Information Report Series, 1993-1995.

Table 24. Estimated age composition of sockeye escapements into Nelson River, 1986-1995.

Year	Sample[a] Size		Age															Total
			0.2	1.1	0.3	1.2	2.1	0.4	1.3	2.2	1.4	2.3	3.2	2.4	3.1	3.3	Other[b]	
1986	416	Percent	0.0	0.0	0.6	1.6	2.4	0.0	7.9	15.7	0.0	71.7	0.0	0.2	0.0	0.0	0.0	100
		Number	0	0	662	1,835	2,755	0	9,235	18,369	0	83,939	0	252	0	0	0	117,047
1987	180	Percent	0.0	0.0	0.0	18.9	0.6	0.0	10.0	67.8	0.0	2.8	0.0	0.0	0.0	0.0	0.0	100
		Number	0	0	0	26,855	790	0	14,218	96,363	0	3,949	0	0	0	0	0	142,175
1988		Percent	0.0	1.3	0.6	18.7	13.1	0.0	14.6	27.1	0.0	24.1	0.4	0.0	0.0	0.0	0.0	100
		Number	0	1,700	800	25,300	17,700	0	19,700	36,600	0	32,600	600	0	0	0	0	135,000
1989	1,055	Percent	0.0	0.0	0.0	14.3	3.5	0.0	7.8	68.0	0.1	5.7	0.0	0.3	0.0	0.0	0.3	100
		Number	0	0	0	27,652	6,843	0	15,049	131,301	101	11,033	0	521	0	0	497	192,997
1990	5,569	Percent	0.0	0.0	0.7	3.2	0.0	0.0	15.6	33.2	0.1	44.6	1.7	0.5	0.0	0.5	0.0	100
		Number	0	0	1,648	7,821	0	0	37,527	79,852	171	107,282	4,040	1,192	0	1,091	75	240,699
1991	1,015	Percent	0.0	0.0	0.1	18.4	1.5	0.0	10.2	53.7	0.0	14.8	0.0	0.0	0.0	0.0	1.3	100
		Number	0	0	222	49,517	3,915	0	27,395	144,133	0	39,851	0	0	0	0	3,367	268,400
1992	733	Percent	0.3	0.0	0.4	19.1	4.6	0.0	10.9	43.9	0.4	20.1	0.0	0.4	0.0	0.0	0.0	100
		Number	502	0	573	30,934	7,453	0	17,751	71,240	574	32,605	0	669	0	0	0	162,301
1993	878	Percent	0.0	0.0	0.1	3.9	3.2	0.0	9.4	53.0	0.0	28.3	2.2	0.0	0.0	0.1	0.0	100
		Number	0	0	109	8,097	6,554	0	19,383	109,755	0	58,558	4,507	0	0	218	0	207,181
1994	1,027	Percent	0.0	0.0	0.0	2.0	4.7	0.0	1.0	84.3	0.4	6.9	0.5	0.1	0.1	0.0	0.0	100
		Number	0	0	0	6,559	15,183	0	3,248	274,106	1,408	22,486	1,625	386	298	0	0	325,299
1995	1,027	Percent	0.1	0.1	0.0	1.3	8.6	0.0	1.4	82.6	0.0	5.6	0.2	0.2	0.0	0.0	0.0	100
		Number	226	226	0	4,141	28,289	0	4,735	271,947	0	18,574	723	537	0	0	0	329,398
Average:	**1,190**	**Percent**	**0.0**	**0.1**	**0.2**	**8.9**	**4.2**	**0.0**	**7.9**	**58.2**	**0.1**	**19.4**	**0.5**	**0.2**	**0.0**	**0.1**	**0.2**	**100.0**
		Number	**73**	**193**	**401**	**18,871**	**8,948**	**0**	**16,824**	**123,367**	**225**	**41,088**	**1,150**	**356**	**30**	**131**	**394**	**212,050**

[a]Samples collected in a beach seine set, 1986-1988 and a fish weir trap, 1989-1995.

[b]Other ages include: 1.1, 0.2, 0.4, 3.1

Source:
Alaska Peninsula and Aleutian Islands Areas Annual Salmon and Herring Management Report, 1988.
Alaska Peninsula and Aleutian Islands Management Area Commercial Salmon Catch and Escapement Statistics, Technical Fishery Report Series, 1989-1992.
Alaska Peninsula Management Area Salmon Escapement and Catch Sampling Results, Regional Information Report Series, 1993-1995.

Table 25. Alaska Peninsula and Unalaska Lakes relative sockeye and coho salmon productivity and percent of total by region.

Lake (morphometry)	RELATIVE Sockeye [a]	PRODUCTIVITY Coho [b]	Lake (Region)	Percent (%) (Sockeye) Total Production [a]
Shallow			***Southcentral***	
Archeredin	low	high	Archeredin	1.3
Big Fish	low	high	John Neslon	0.5
Ilnik	low	high	Orzinski	0.9
Kashega	low	high	Red Cove	0.6
Mortensen	low	high	Wosnesenski	1.1
Morzhovoi	low	high	Total:	4.4
Sandy	low	high		
Southwest Coast	low	high	***Cold Bay***	
Swede	low	high		
Thin Point	low	high	Charlie Hansen	1
Volcano, Upper	low	high	Mortensen	0.1
Wosnesenski	low	high	Morzhovoi	1.8
			Swede	0.6
Intermediate			Thin Point	2.3
			Total:	5.8
Charlie Hansen	low	high		
John Nelson	low	high	***Northcentral***	
McLees	low	moderate		
Orzinski	low	high	Bear	66.7
Red Cove	low	high	Big Fish	1.6
Summer Bay	low	high	Ilnik	0.9
Unalaska	low	high	Sandy	3.2
Volcano, Lower	low	high	Sapsuk	12.8
Wildman	low	high	Southwest Coast	1.6
			Wildman	1.5
Deep			Total:	88.3
Bear	high	moderate	***Unalaska Island***	
Sapsuk	high	moderate		
			Kashega	0.5
			McLees	0.6
			Summer Bay	0
			Unalaska	0.1
			Volcano, Lower	0.4
			Volcano, Upper	0.2
			Total:	1.8

[a] Based on surface area except derived from zooplankton model for Bear and Sapsuk.

[b] Based on euphotic volume to surface area ratio.

Table 26. Summary of limnological and fishery data collected from 23 Alaska Peninsula and Unalaska Island Lakes, 1993-1995.

Lake	Region	Surface Area (km^2)	Mean depth (m)	Turbidity (NTU)	Chlor-a (ug/L)	Total - P 1m (ug/L)	Total N to Total P (TN:TP)	Zooplankton biomass (mg/m^2)[a]	Mean Escapement[b]
Shallow									
Acheredin	SC	9.2	0.9	1.7	0.76	5.7	58.6	3	4,070
Wosnesenski	SC	7.2	0.9	4.4	1.52	18.0	25.3	8.34	nd
Mortensen	CB	0.6	0.9	8.7	15.60	76.8	14.3	55.56	6,840
Morzhovoi	CB	12.3	1.4	21.2	40.98	225.7	18.5	192.48	18,900
Swede	CB	3.9	2.1	1.0	0.78	8.5	29.8	2.43	590
Thin Point	CB	15.9	1.9	10.4	5.24	39.1	14.2	0.17	24,599
Big Fish	NC	11.2	1.3	20.8	13.45	105.1	26.8	9.83	4,670
Ilnik	NC	6.3	1.0[c]	3.7	3.64	79.8	5.7	2.82	51,773
Sandy	NC	21.6	2.4	4.7	0.92	11.7	12.1	15.7	54,640
Southwest Coast	NC	10.6	1.3	21.1	31.09	134.0	25.4	159.11	1,710
Kashega	UN	3.2	0.9	0.4	0.49	5.1	32.2	0.7	7,267
Volcano, Upper	UN	1.6	1.3	1.8	1.24	15.8	15.7	1	2,433
Intermediate									
John Nelson*	SC	3.2	6.9	0.7	2.31	11.9	77.2	487	500
Orzinski*	SC	6	7.8	1.2	1.59	7.8	43.1	189.71	24,132
Red Cove*	SC	3.9	7.7	1.0	1.66	7.3	69.8	189	nd
Charlie Hansen	CB	7	4.2	1.2	0.67	6.5	22.8	40	1,567
Wildman	NC	9.9	5.2	4.8	21.78	188.2	7.3	2629	25,920
McLees	UN	4	6.0	1.2	1.68	11.8	19.6	152	2,690
Summer Bay	UN	0.2	5.8	1.2	1.78	7.2	32.2	95	450
Unalaska	UN	0.4	4.8	1.1	0.66	4.1	39.1	3	98
Volcano, Lower	UN	2.9	6.4	0.5	0.76	7.4	25.2	12	nd
Deep									
Bear	NC	25.6	32.3	1.1	0.90	3.7	64.5	1847	433,620
Sapsuk	NC	11	40.4	0.6	1.07	3.3	43.2	944	208,350

*Saline lakes .

SC=Southcentral; CB=Cold Bay; NC=Northcentral ; UN=Unalaska Island

[a] 1994 samples

[b] 1986-1995 except for Bear, 1985-1995; for Sapsuk , escapements at Nelson River.

[c] preliminary estimate.

nd = no data

Table 27. Potential production, limitations and unknown factors for sockeye salmon production, and potential enhancement strategies, and risks, for 23 Alaska Peninsula and Unalaska Island Lakes.

Lake	Potential production[a]	Limitations for sockeye production	Unknown factors for sockeye production	Potential enhancement strategy	Potential risks of enhancement
Shallow					
Acheredin	50,600	phosphorous, chlor-a, zooplankton	winter DO, run size, spawning capacity, juvenile production data	smolt imprinting	holdover impacts; straying
Wosnesenski	39,600	zooplankton	winter DO, escapement, spawning capacity, juvenile production data	smolt imprinting	holdover impacts; straying
Mortensen	3,300	zooplankton	winter DO, run size, spawning capacity, juvenile production data	presmolt or smolt stocking	intraspecies competition
Morzhovoi	67,650	turbidity	winter DO, run size, spawning capacity, juvenile production data	presmolt or smolt stockingb	intra- and interspecies competition
Swede	21,450	zooplankton	winter DO, run size, spawning capacity, juvenile production data	none	NA
Thin Point	87,450	zooplankton	winter DO, run size, spawning capacity, juvenile production data	presmolt or smolt stockingb	intra- and interspecies competition
Big Fish	61,600	zooplankton	winter DO, spawning capacity, juvenile production data	smolt imprinting	holdover impacts; straying
Ilnik	34,650	zooplankton	winter DO, run size, spawning capacity, juvenile production data	smolt imprinting	holdover impacts; straying
Sandy	118,800	zooplankton	winter DO, run size, spawning capacity, juvenile production data	presmolt or smolt stocking	intraspecies competition
Southwest Coast	58,300	turbidity	winter DO, run size, spawning capacity, juvenile production data	smolt imprinting	holdover impacts; straying
Kashega	17,600	phosphorous, chlor-a, zooplankton	winter DO, run size, spawning capacity, juvenile production data	lake fertilization	none
Volcano, Upper	8,800	zooplankton	winter DO, run size, spawning capacity, juvenile production data	smolt imprinting	holdover impacts; straying
Intermediate					
John Nelson*	17,600	salinity, outlet barrier	run size, spawning capacity, juvenile production data	barrier removal	none
Orzinski*	33,000	salinity	winter DO, run size, spawning capacity, juvenile production data	smolt imprintingb	holdover impacts; straying
Red Cove*	21,450	phosphorous, chlor-a, salinity, outlet barrier	escapement, spawning capacity, juvenile production data	barrier removal, smolt imprintingb	holdover impacts; straying
Charlie Hansen	38,500	phosphorous, chlor-a, escapement, spawning habitat	run size, spawning capacity, juvenile production data	presmolt or smolt stocking	holdover impacts; straying
Wildman	54,450	zooplankton size, escapement	escapement, spawning capacity, juvenile production data	fry stocking	intraspecies competition
McLees	22,000	chlor-a	run size, spawning capacity, juvenile production data	presmolt or smolt stocking	holdover impacts; straying
Summer Bay	1,100	zooplankton	run size, spawning capacity, juvenile production data	presmolt or smolt stocking	holdover impacts; straying
Unalaska	2,200	phosphorous, chlor-a, zooplankton	HRT, escapement, spawning capacity, juvenile production data	fertilization, presmolt stocking	intraspecies competition
Volcano, Lower	15,950	phosphorous, chlor-a, zooplankton	escapement, spawning capacity, juvenile production data	presmolt or smolt stocking	holdover impacts; straying
Deep					
Bear	2,500,000	spawning habitat	early run size, juvenile production, early-late run interactions	fry stocking	intraspecies (early and late run)competition
Sapsuk	480,000	spawning habitat	escapement, juvenile production data	fry stocking	intra- and interspecies competition

*Saline lakes.

[a] estimated from surface area model for all lakes except for Bear and Sapsuk Lakes, in which the zooplankton model was used.

b experimental fry stocking may be an option.

DO = dissolved oxygen

HRT = hydraulic residence time

NA = not applicable

Table 28. Recommendations for enhancement, including technique, stocking level, and potential production.

Fry Stocking (May-June)	Stocking Level	Potential Adult Production[a]
Bear Lake	5-10 million, initial ~2-4 million increases every 3 years maximum - 20 million	300,000
Sapsuk Lake	2-3 million, initial 0.5 million increases every 3 years maximum - 5 million	75,000
Wildman Lake	2-3 million, initial ongoing assessment, thereafter	45,000
	Total:	420,000
Presmolt Stocking (October-November)		
Morzhovoi Lake	50,000-100,000, initial ongoing assessment, thereafter	10,000
Thin Point Lake	50,000-100,000, initial ongoing assessment, thereafter	10,000
Sandy Lake	50,000-100,000, initial ongoing assessment, thereafter	10,000
Charlie Hansen Lake	50,000-100,000, initial ongoing assessment, thereafter	10,000
McClees Lake	50,000-100,000, initial ongoing assessment, thereafter	10,000
Summer Bay Lake	50,000-100,000, initial ongoing assessment, thereafter	10,000
Lower Volcano Lake	50,000-100,000, initial ongoing assessment, thereafter	10,000
	Total:	70,000

- Continued -

Table 28. (page 2 of 2)

Smolt Stocking (May-June)	Stocking Level	Potential Adult Production[a]
Archeredin Lake	50,000, initial ongoing assessment, thereafter	7,500
Mortensen Lake	50,000, initial ongoing assessment, thereafter	7,500
Swede Lake	50,000, initial ongoing assessment, thereafter	7,500
Big Fish Lake	50,000, initial ongoing assessment, thereafter	7,500
Ilnik Lake	50,000, initial ongoing assessment, thereafter	7,500
SW Coast Lake	50,000, initial ongoing assessment, thereafter	7,500
Kashega	50,000, initial ongoing assessment, thereafter	7,500
Upper Volcano Lake	50,000, initial ongoing assessment, thereafter	7,500
Orzinski Lake	50,000, initial ongoing assessment, thereafter	7,500
		Total: 67,500
Lake Fertilization (June-August)		
Unalaska Lake	to be determined after HRT is calculated	NA
Barrier Removal		
John Nelson Lake		NA
Red Cove Lake		NA

[a] survival rates: 1.5% - fry; 10% - presmolt; 15% smolt (Honnold and Clevenger 1995)
NA = not applicable
HRT = hydraulic residence time

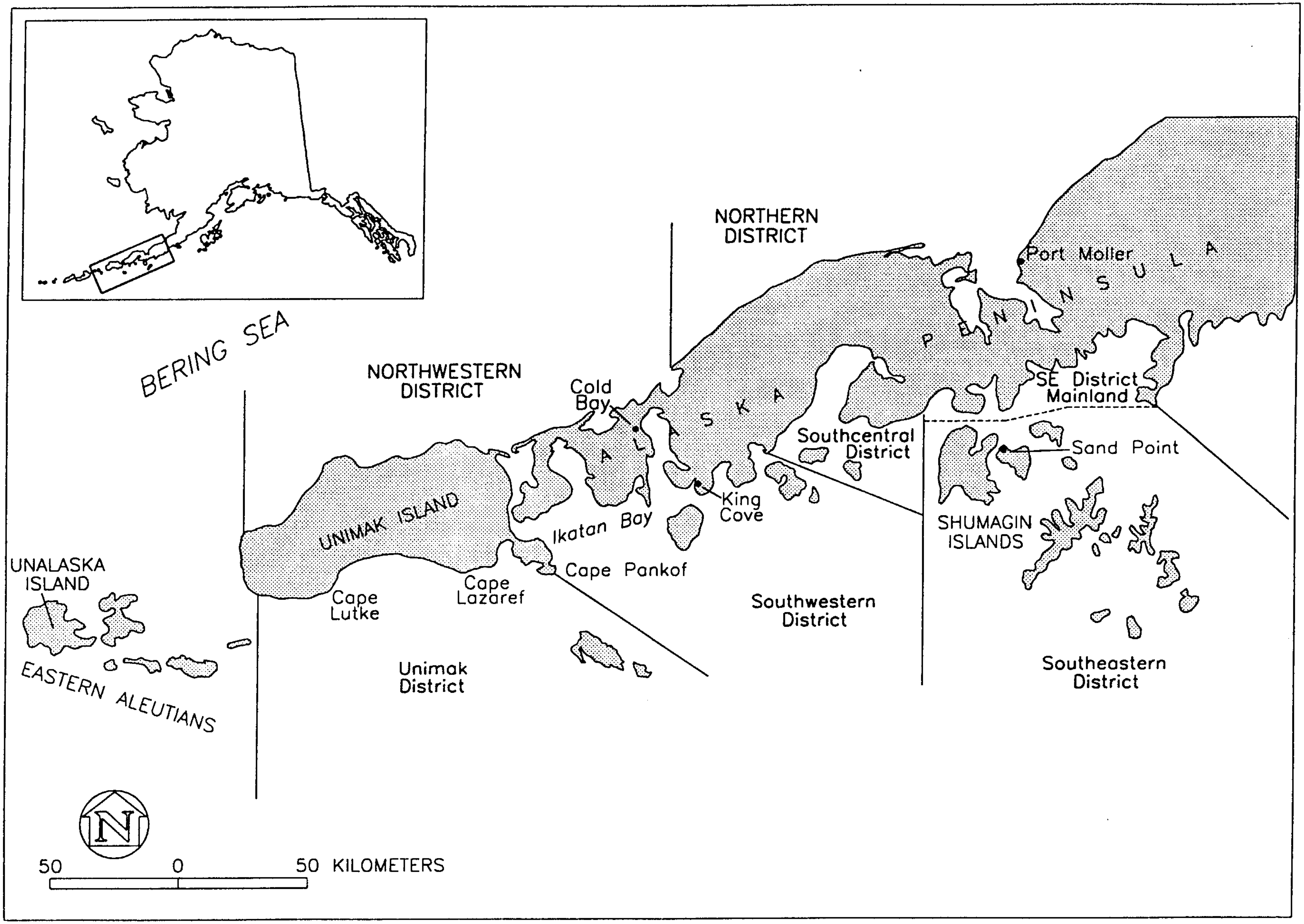


Figure 1. Map of Alaska Peninsula and Eastern Aleutian Islands Fishery Management Districts.

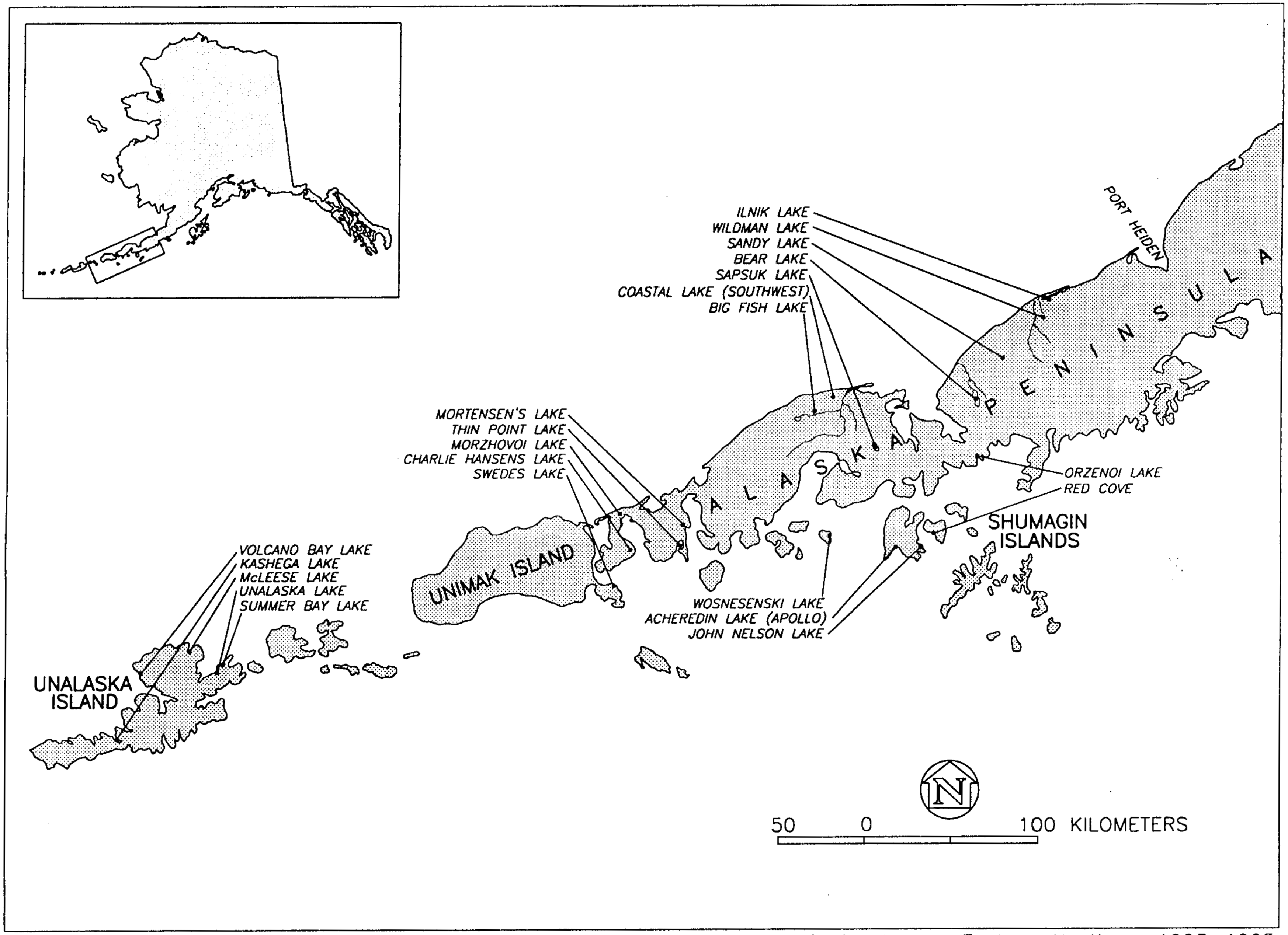
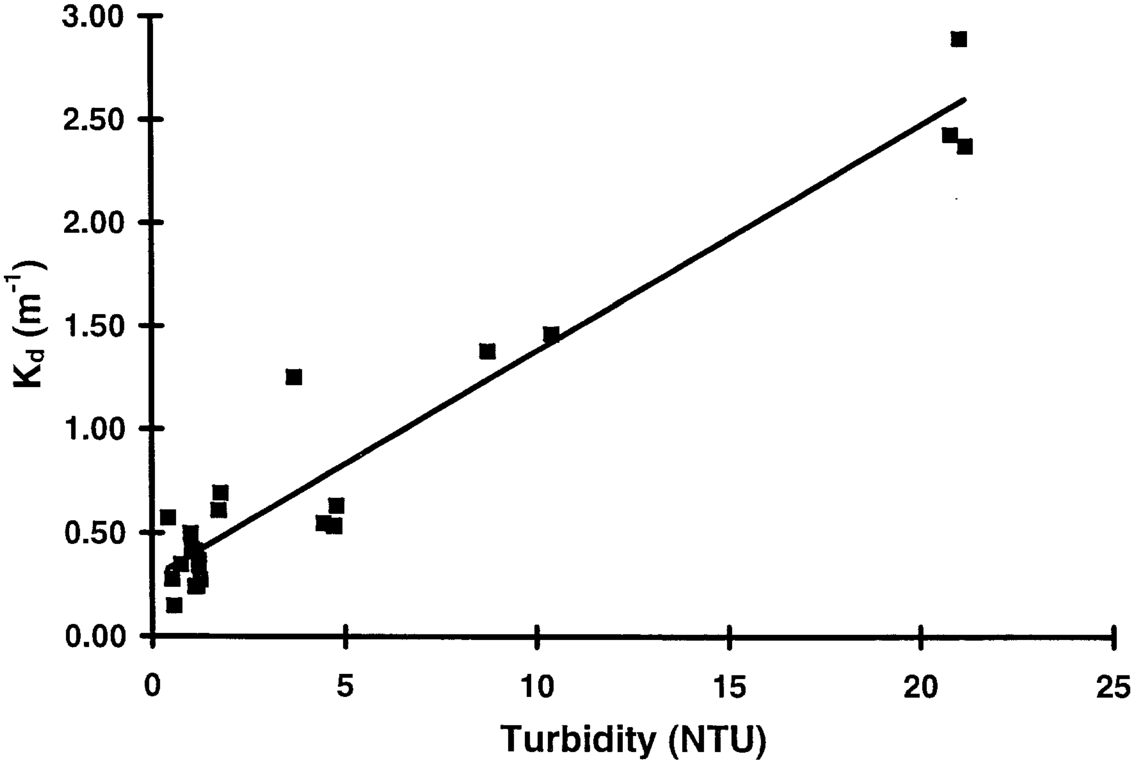


Figure 2. Map showing geographic location of lakes sampled in the Alaska Peninsula and Eastern Aleutians, 1993–1995.

A



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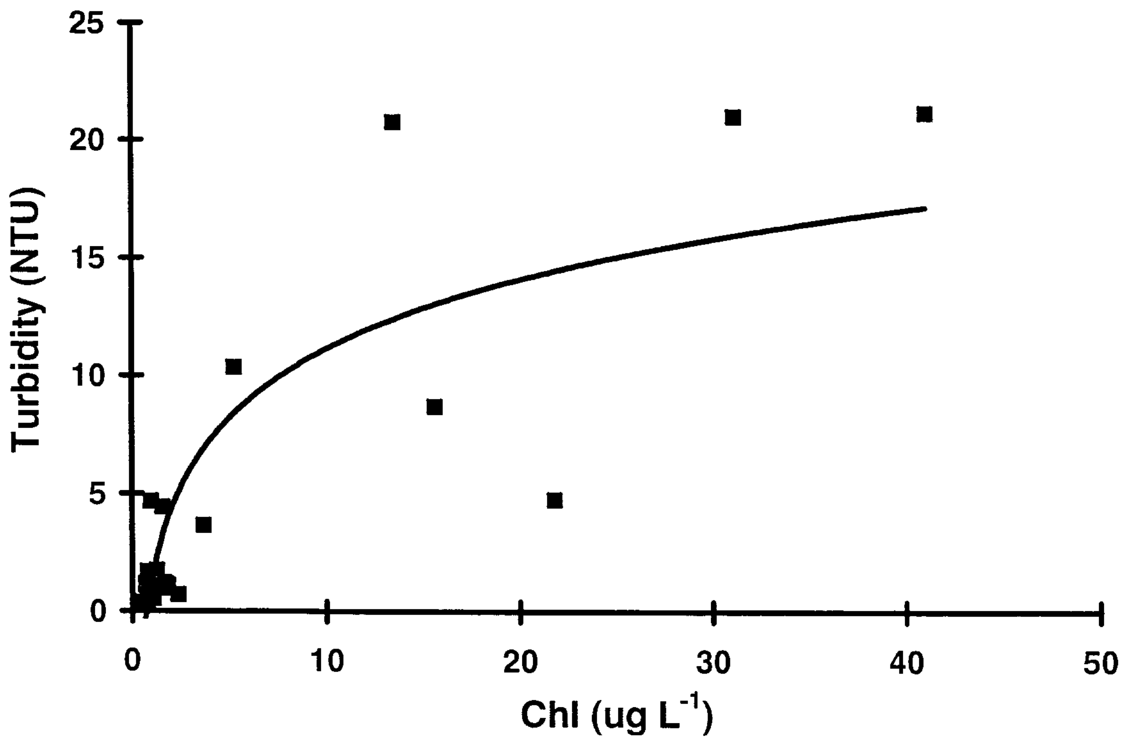
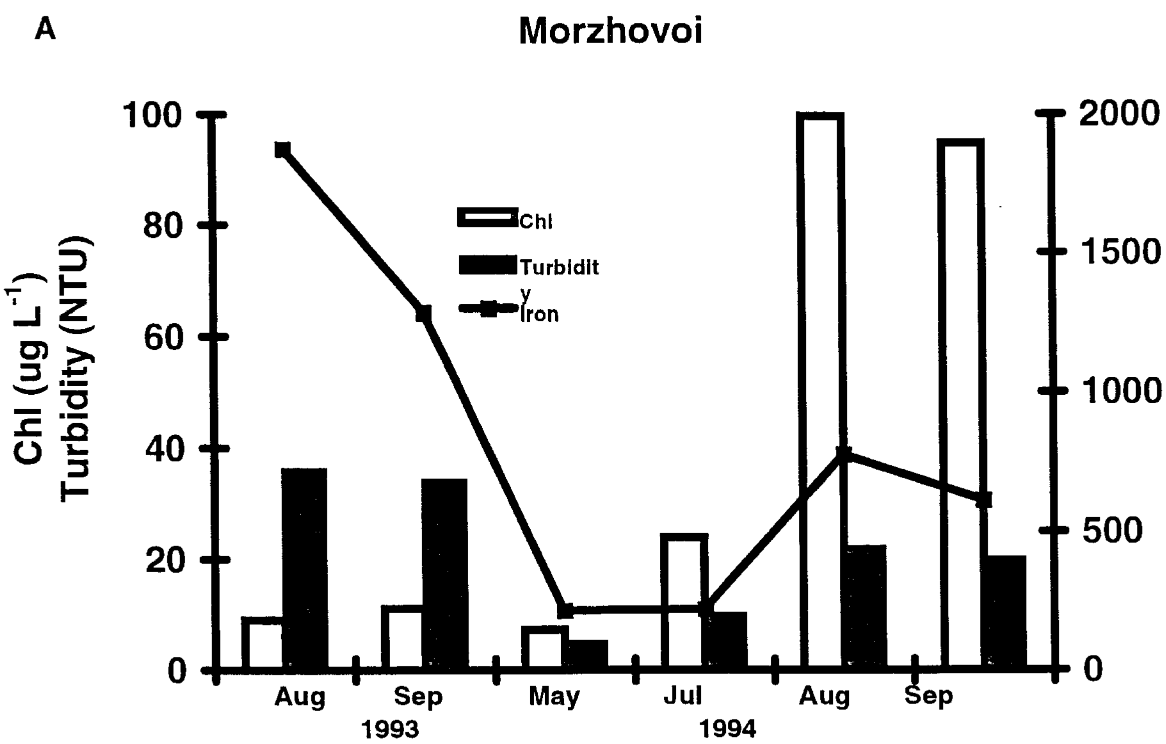


Figure 3. Relationship between vertical extinction coefficient (Kd) and turbidity (A), and (B) the non-linear relationship between turbidity and chlorophyll (Chl) concentration for the 23 study lakes.



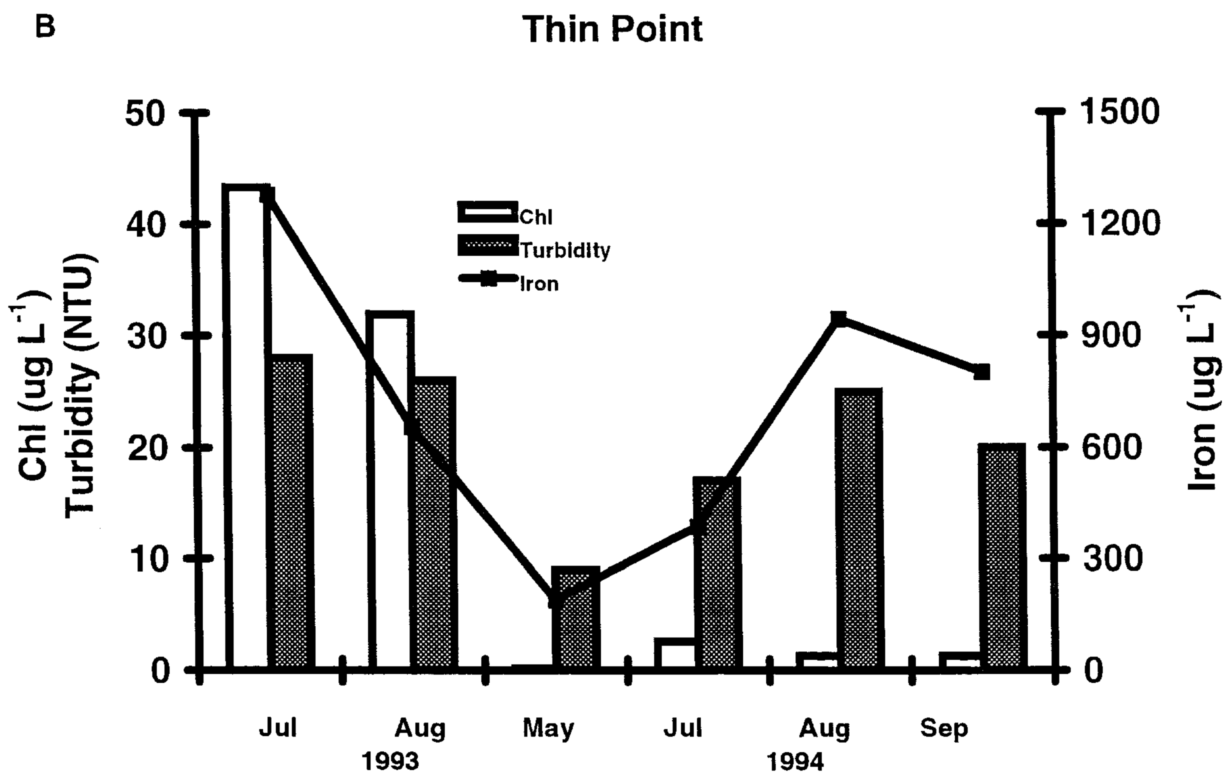


Figure 4. Seasonal changes in turbidity, chlorohpyll (Chl) and iron in (A) Morzhovoi and (B) Thin Point lakes. Note the similar trend between turbidity and iron.

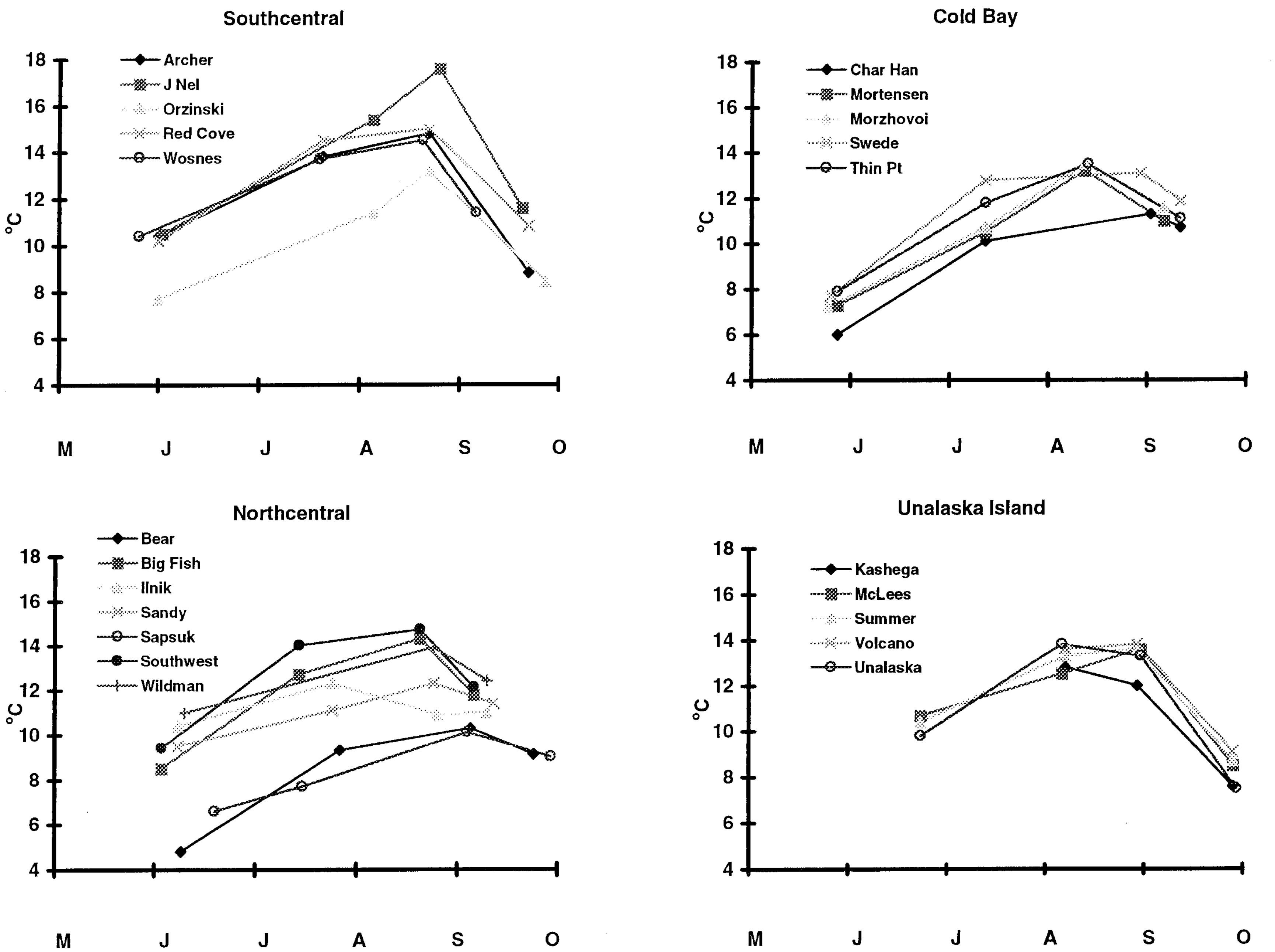


Figure 5. Seasonal changes in temperature (°C) in the 1-m stratum for the 23 Alaskan Peninsula-Aleutian Islands area study lakes, 1994.

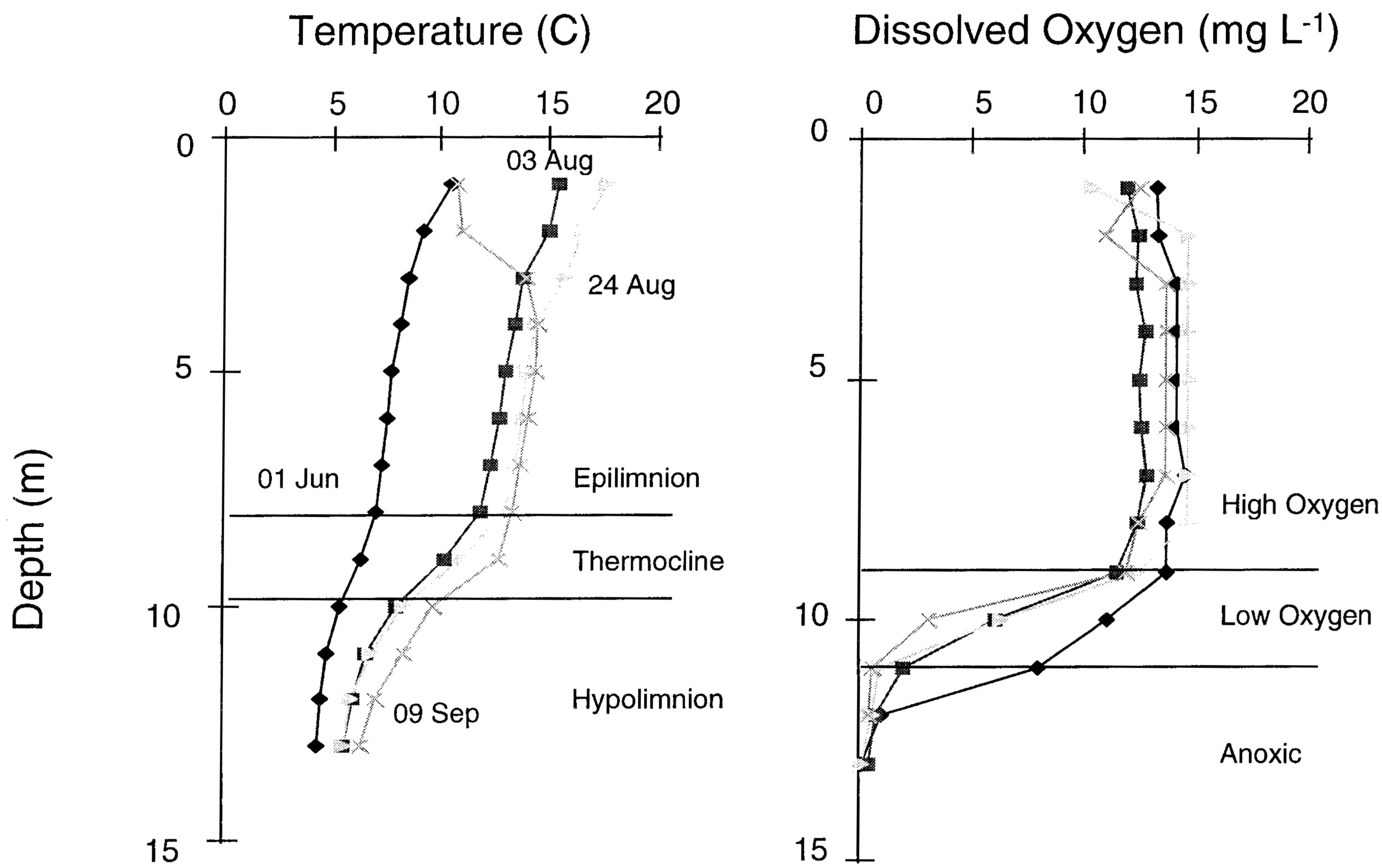


Figure 6. Temperature and dissolved oxygen profiles for John Nelson Lake in 1994 showing thermal stratification and pronounced hypolimnetic oxygen depletion.

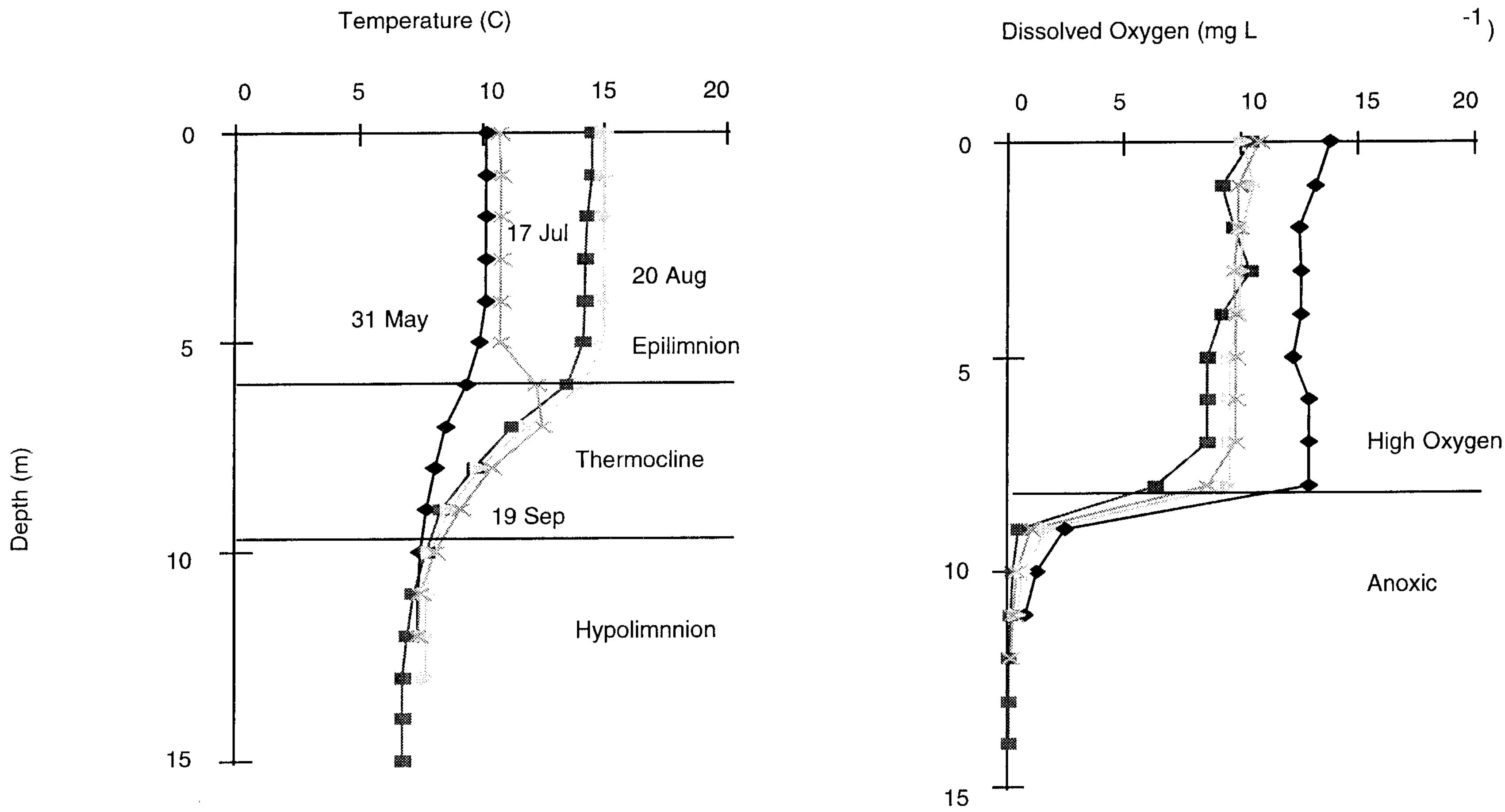


Figure 7. Temperature and dissolved oxygen profiles for Red Cove Lake in 1994 showing thermal stratification and pronounced hypolimnetic oxygen depletion.

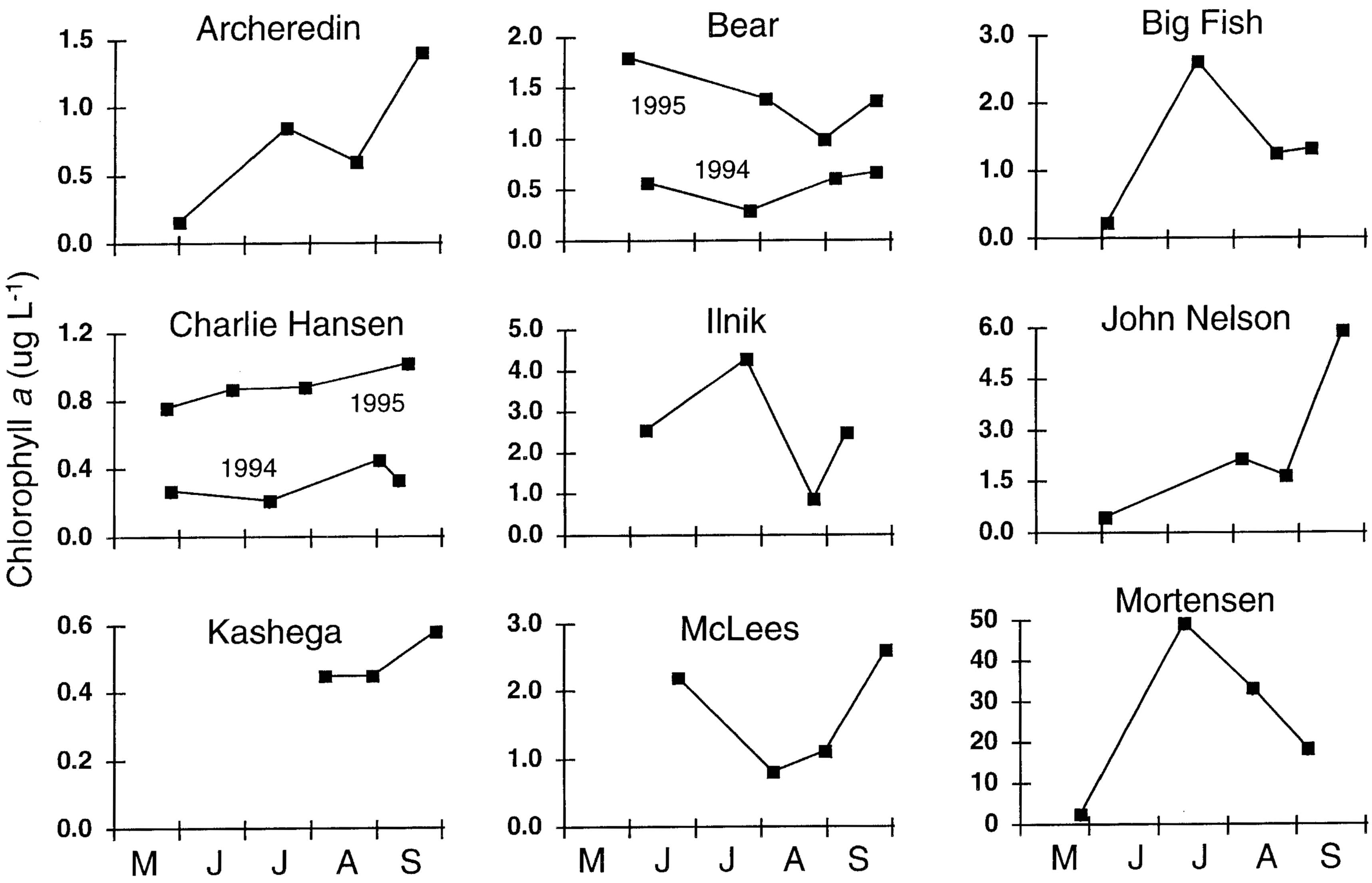


Figure 8. Seasonal (May-September) changes in chlorophyll concentration within the 1-m stratum for the 23 Alaska Peninsula-Aleutian Islands area study lakes, 1994.

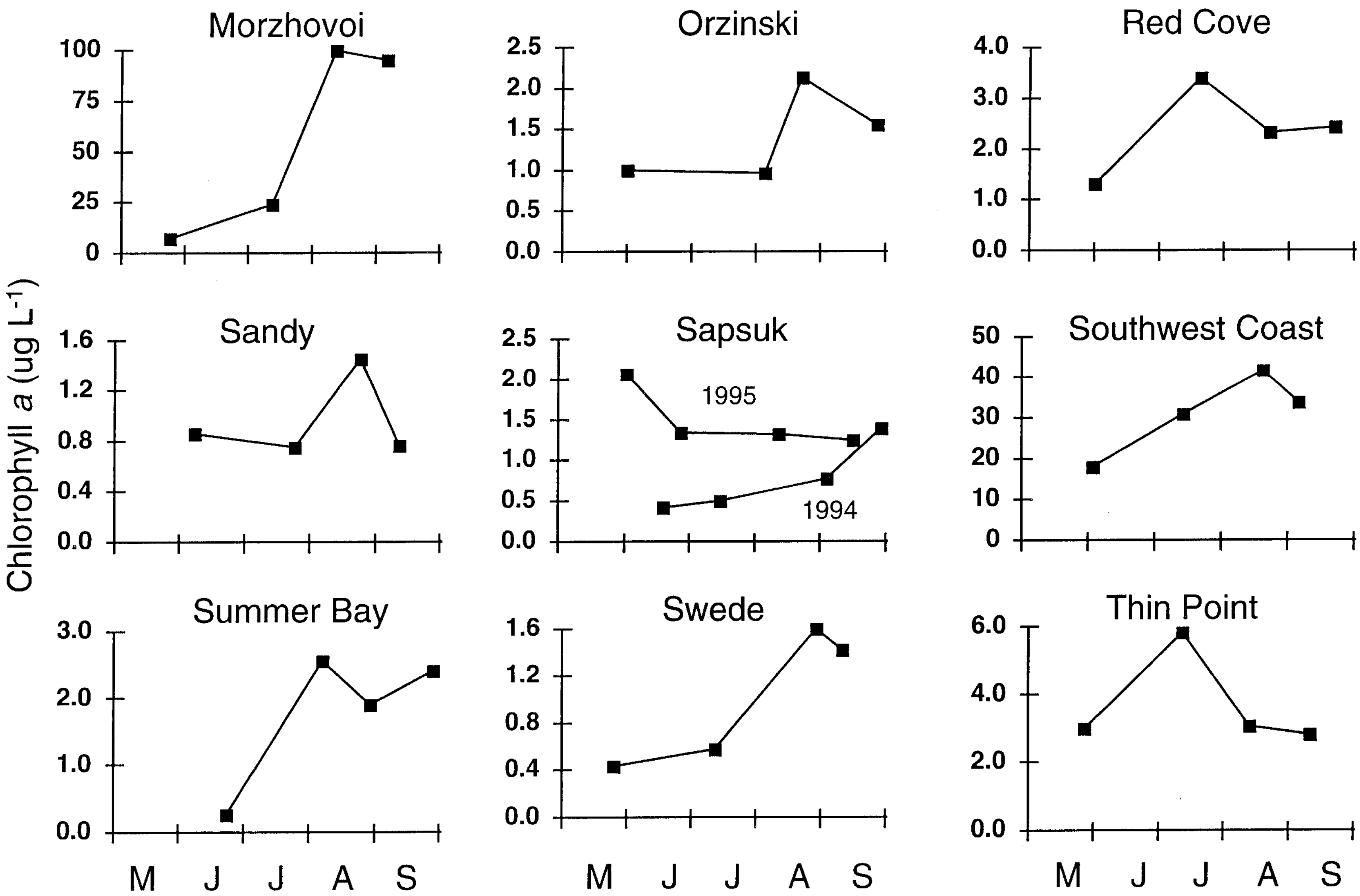


Figure 8. (page 2 of 3)

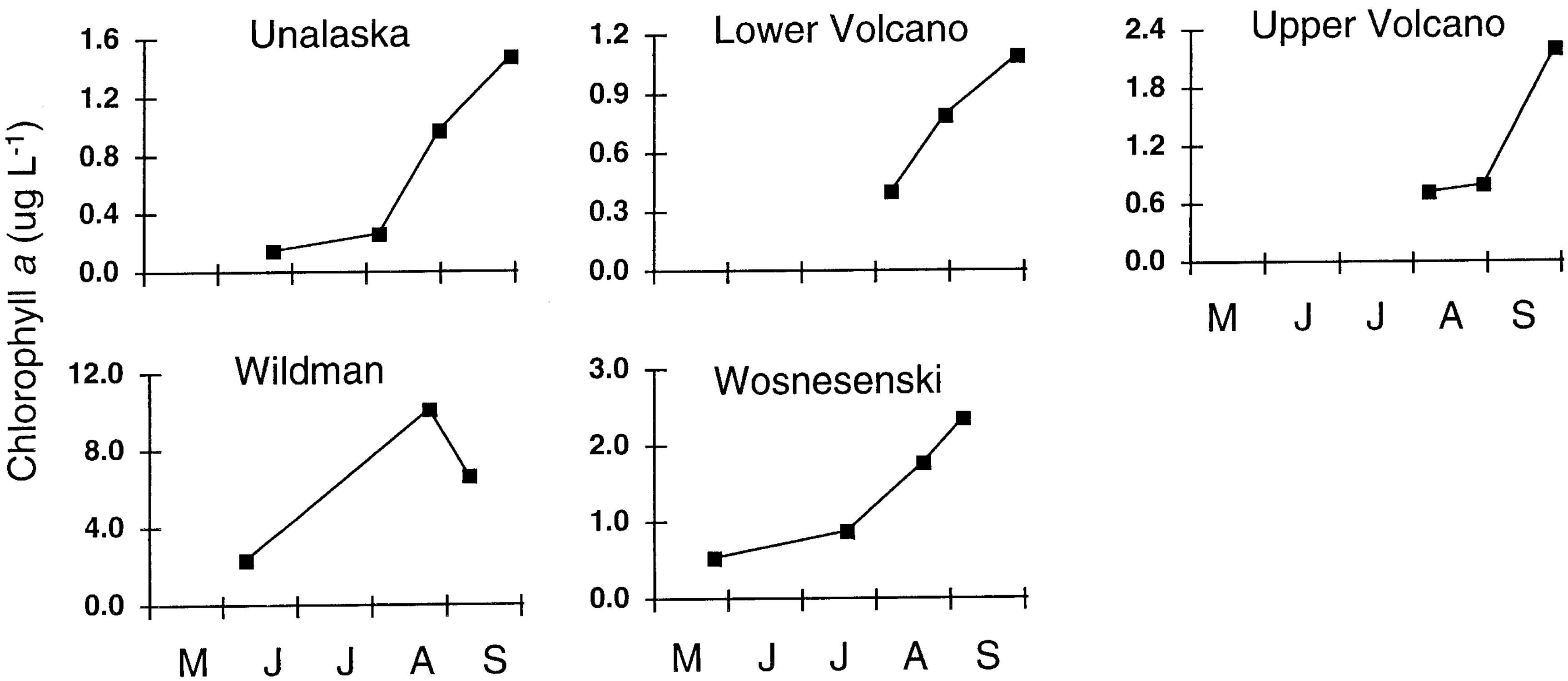


Figure 8. (page 3 of 3)

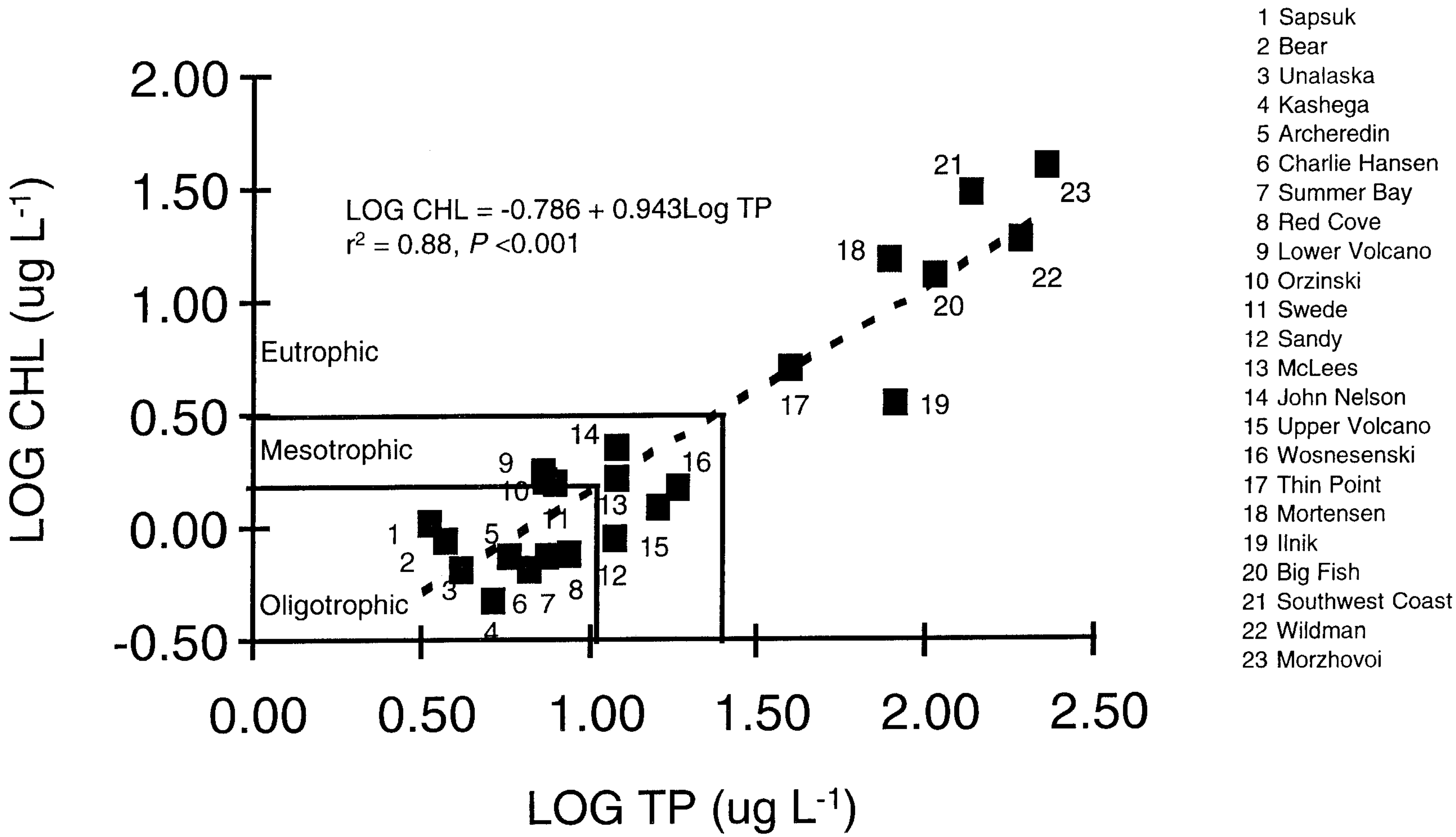


Figure 9. Phosphorus-chlorophyll (chl) regression plot of the 23 Alaska Peninsula-Aleutian Islands area study lakes. Trophic classifications are based on total phosphorus (TP) concentration.

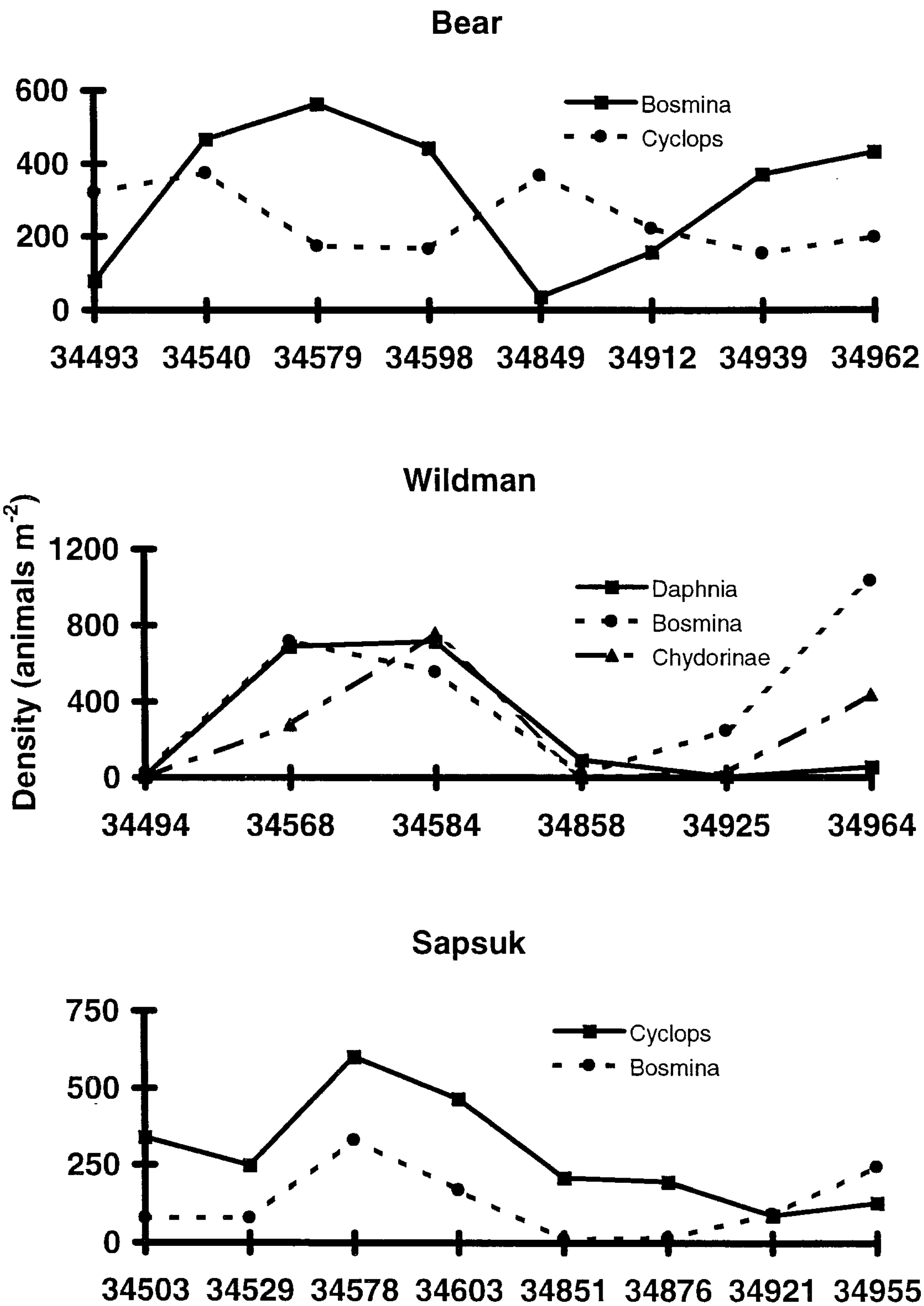


Figure 10. Seasonal changes in density of the major macrozooplankton taxa in Bear, Wildman, and Sapsuk Lakes, 1994-1995. Date interval is not to scale.

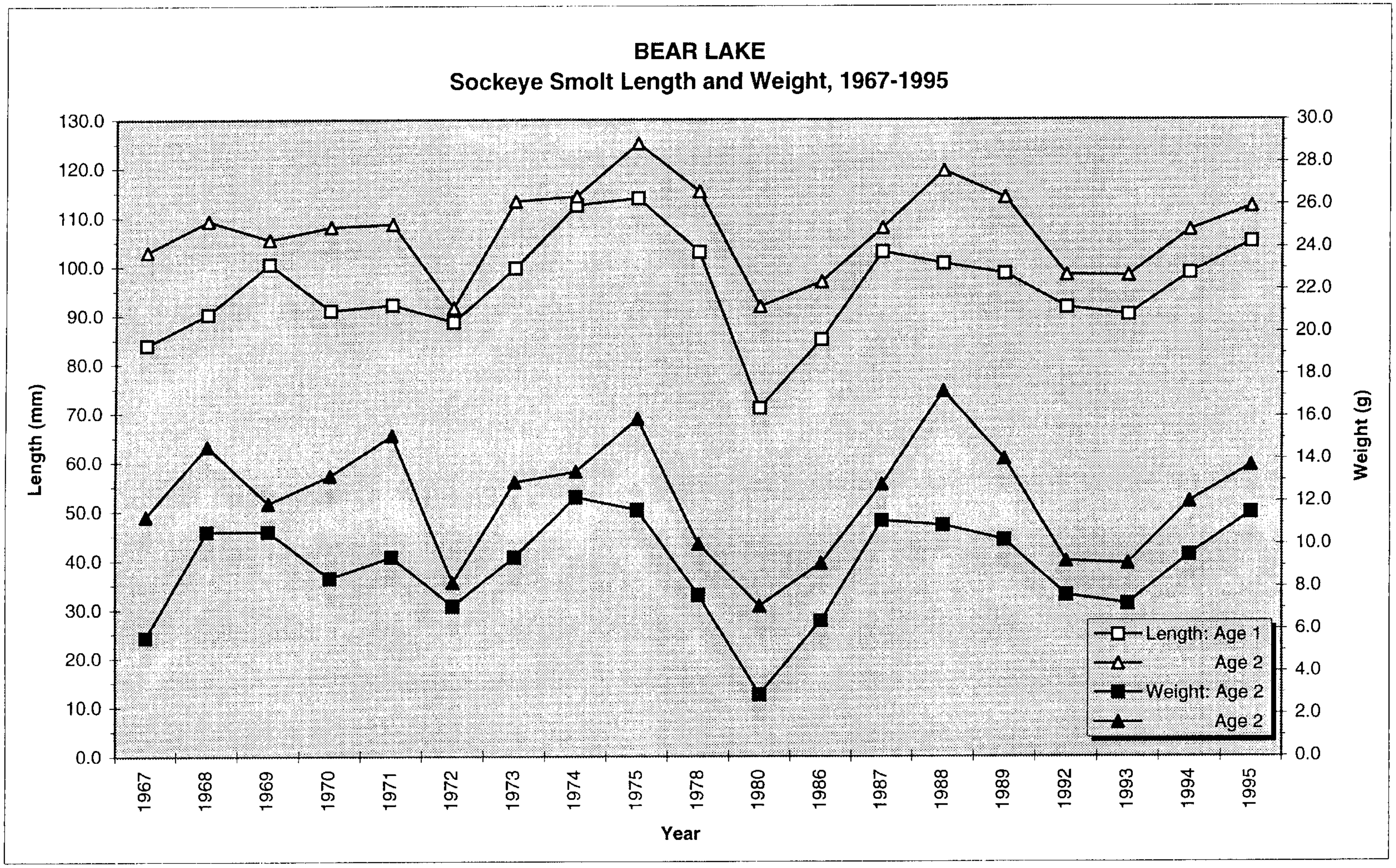


Figure 11. Length and weight of outmigrating age-1, and age-2, sockeye salmon smolt, Bear Lake, 1967 - 1995.

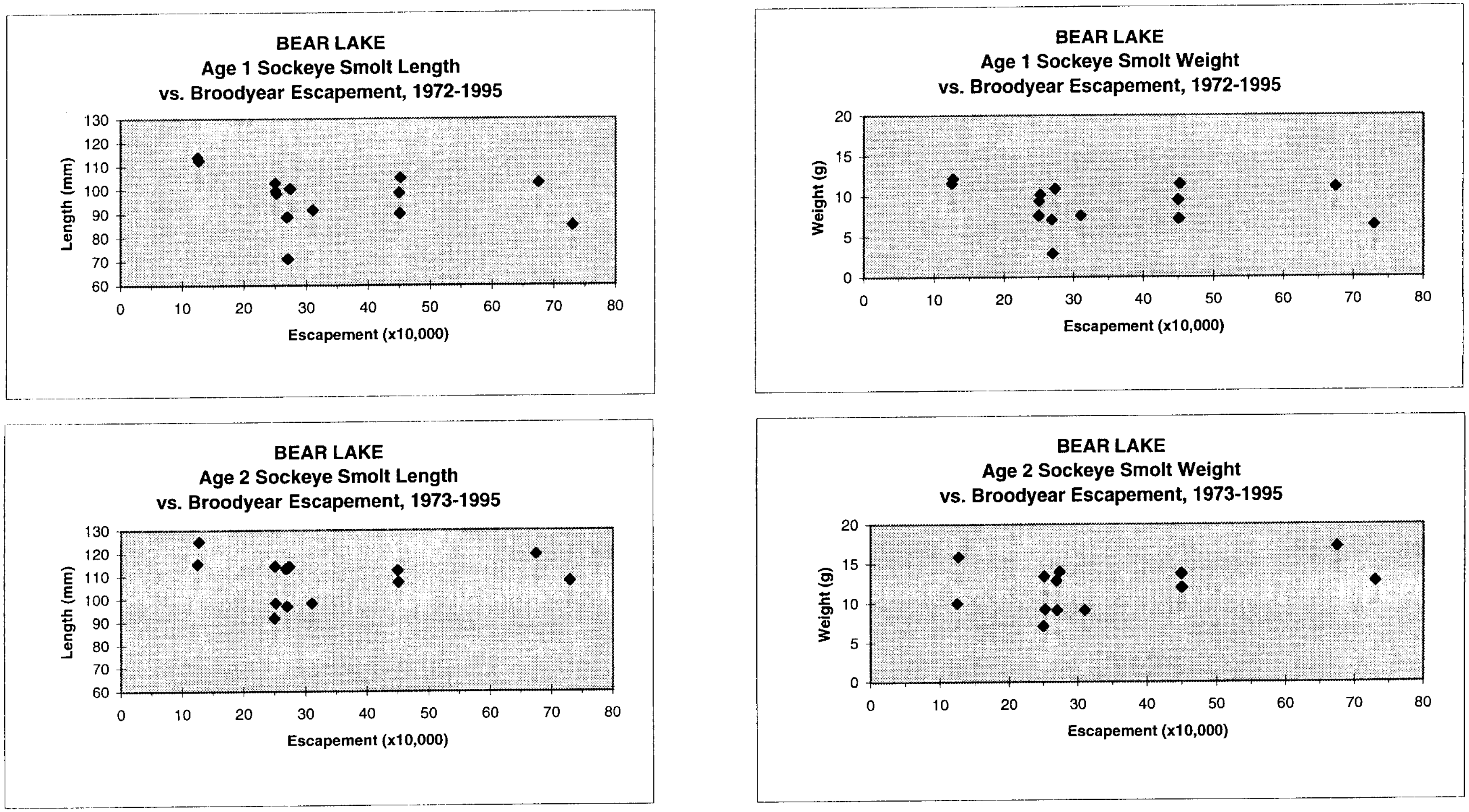
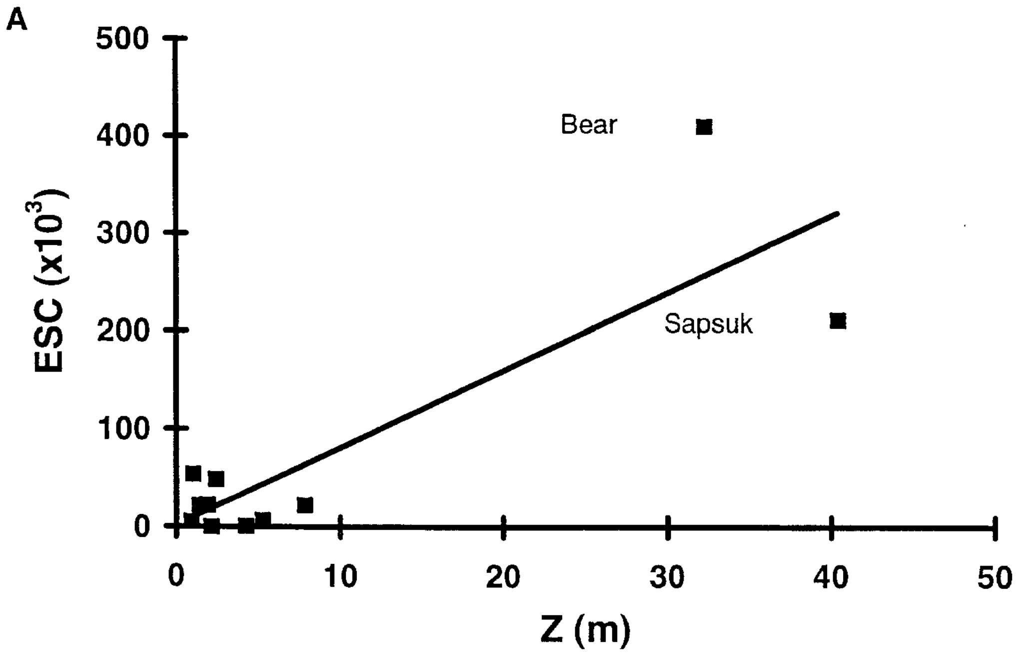


Figure 12. Outmigrating sockeye salmon smolt versus broodyear escapement, Bear Lake, 1972-1995 (age 1) and 1973-1995 (age 2).



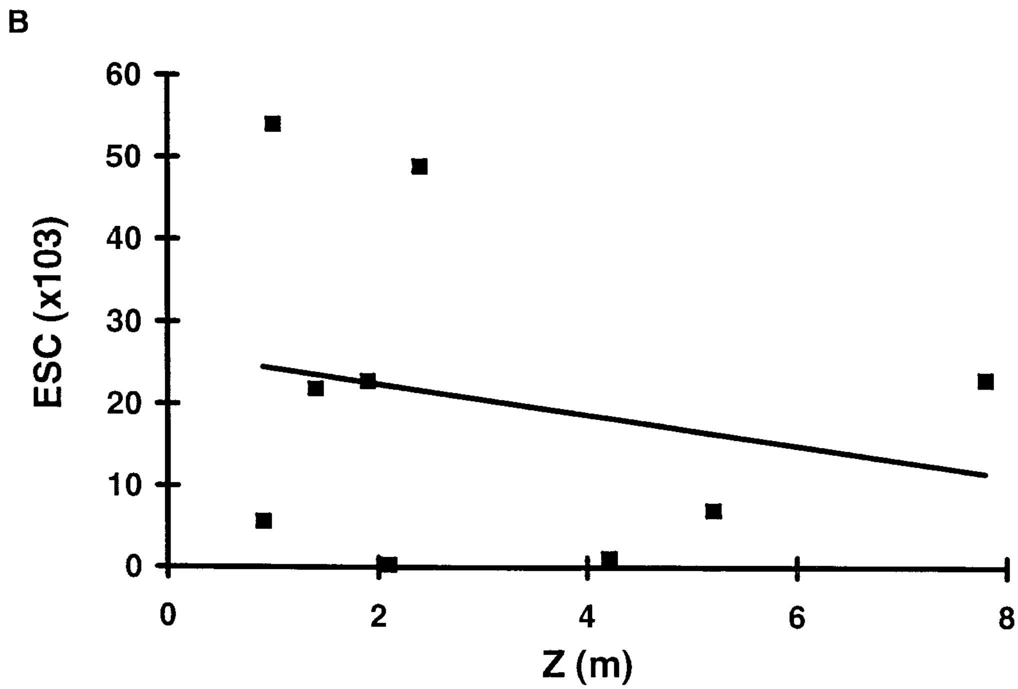


Figure 13. Relationship between mean depth (Z) and mean sockeye escapement (ESC) for 11 Alaska Peninsula lakes (A); (B) as in A, but without Bear and Sapsuk Lakes showing the non-correspondence between ESC and Z.

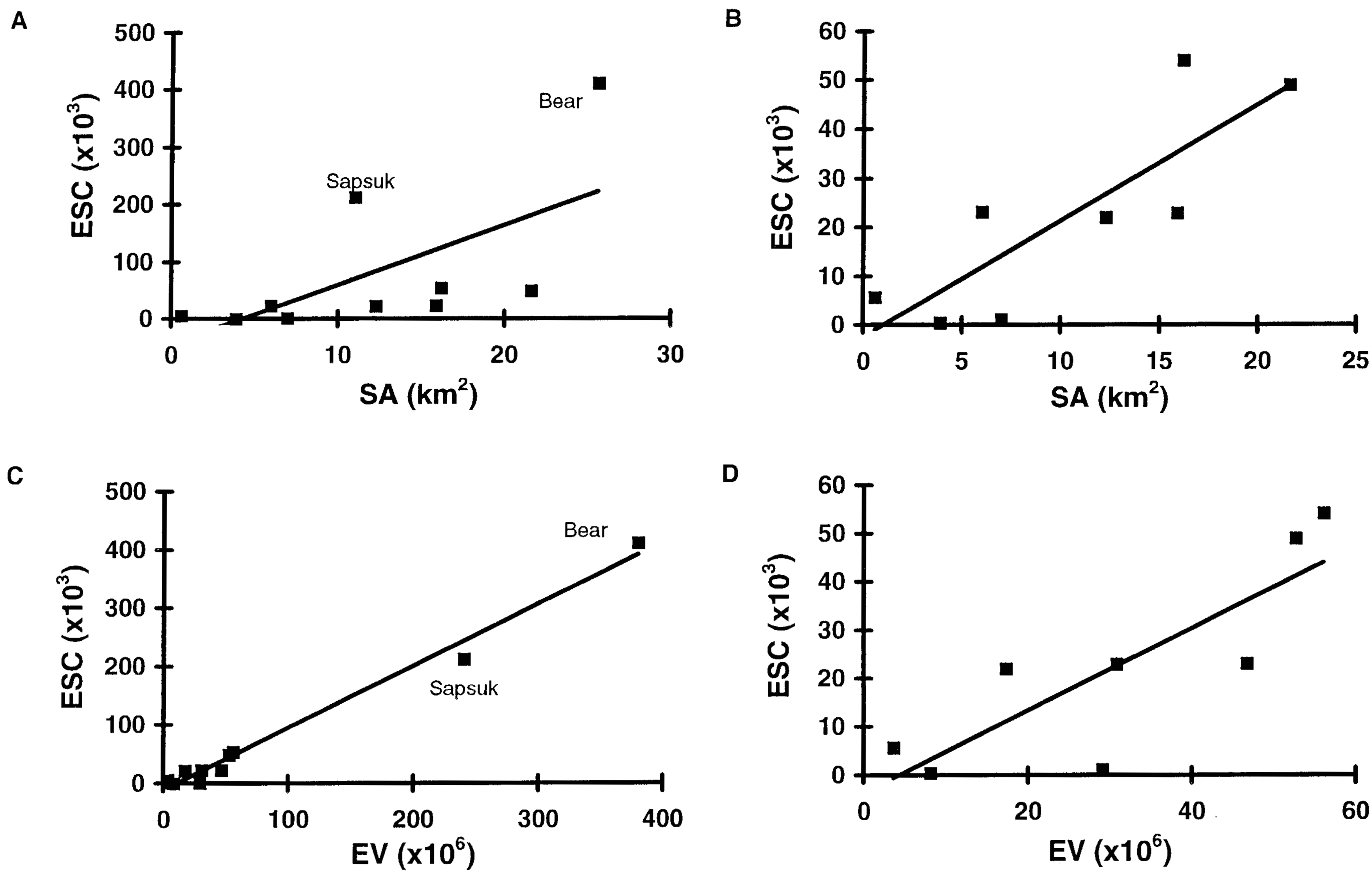


Figure 14. Relationship between surface area (SA) and mean (1986-95) sockeye escapement (ESC) for 10 Alaska Peninsula lakes (A); (B) as in A, but without Bear and Sapsuk Lakes. Relationship between euphotic volume (EV) and ESC for the 10 lakes (C); (D) as in C, but without Bear and Sapsuk Lakes.

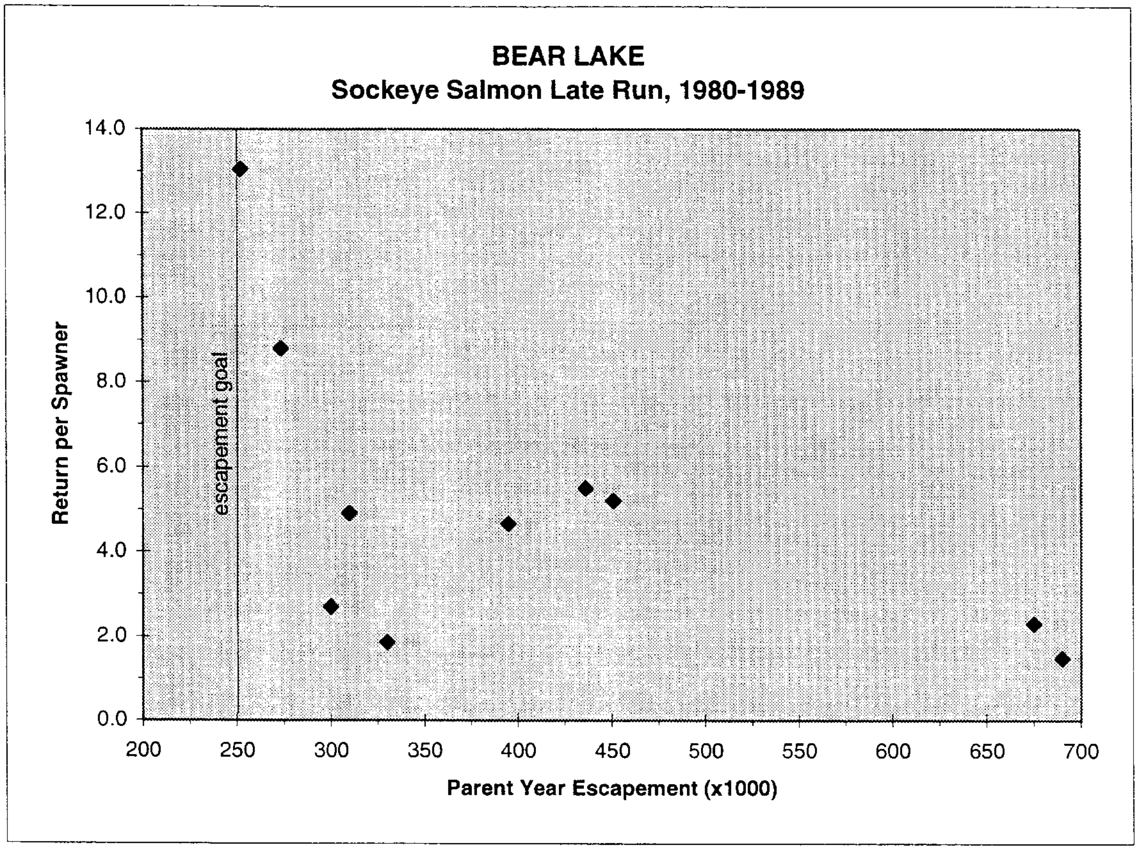


Figure 15. Return per spawner of late run sockeye salmon as a function of parent year escapement, Bear Lake, 1980-1989.

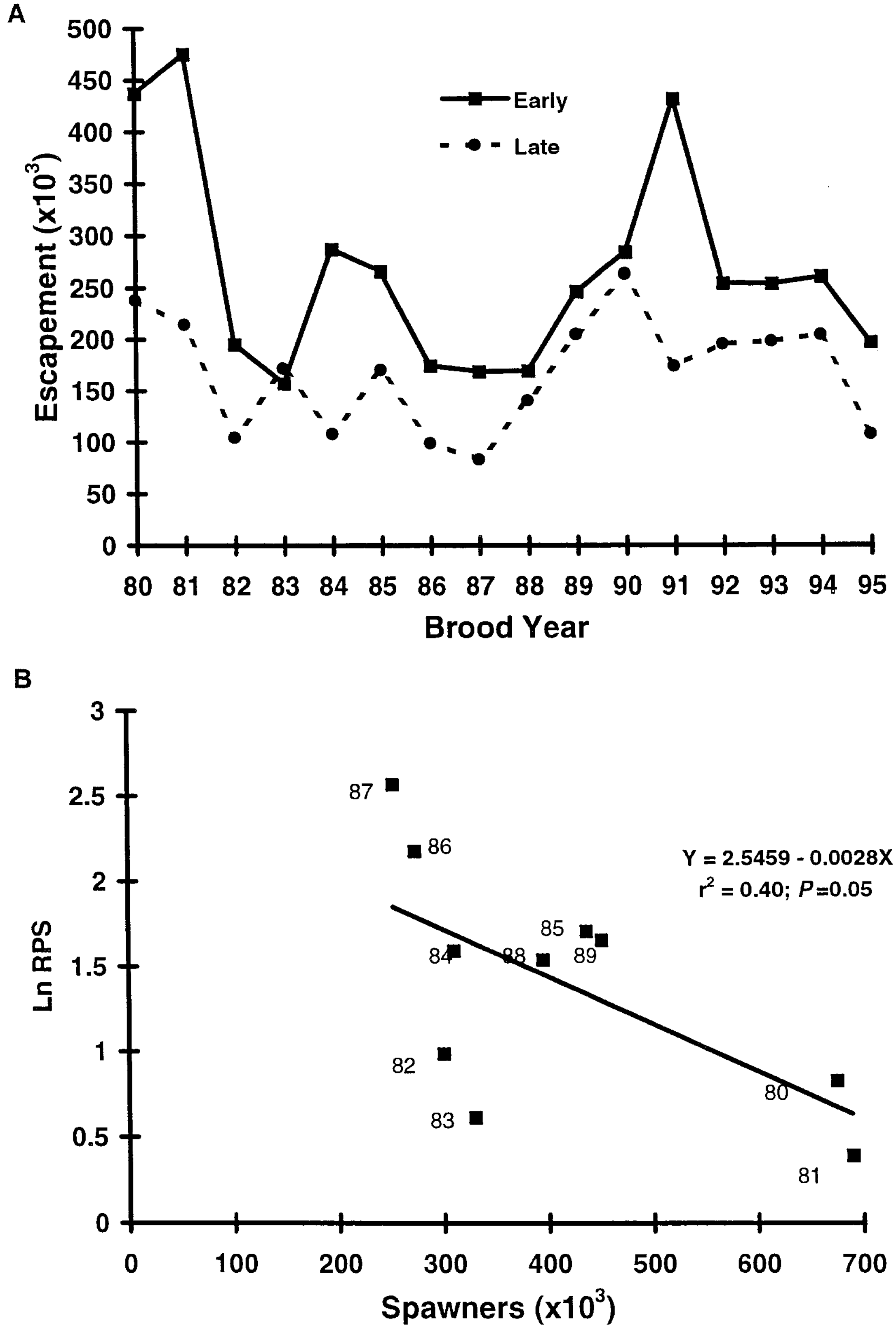


Figure 16. Early and late run sockeye escapement for Bear Lake, 1980-1995 (A); Ricker model of return-per-spawner (RPS) for Bear Lake, 1980-1989 (B).

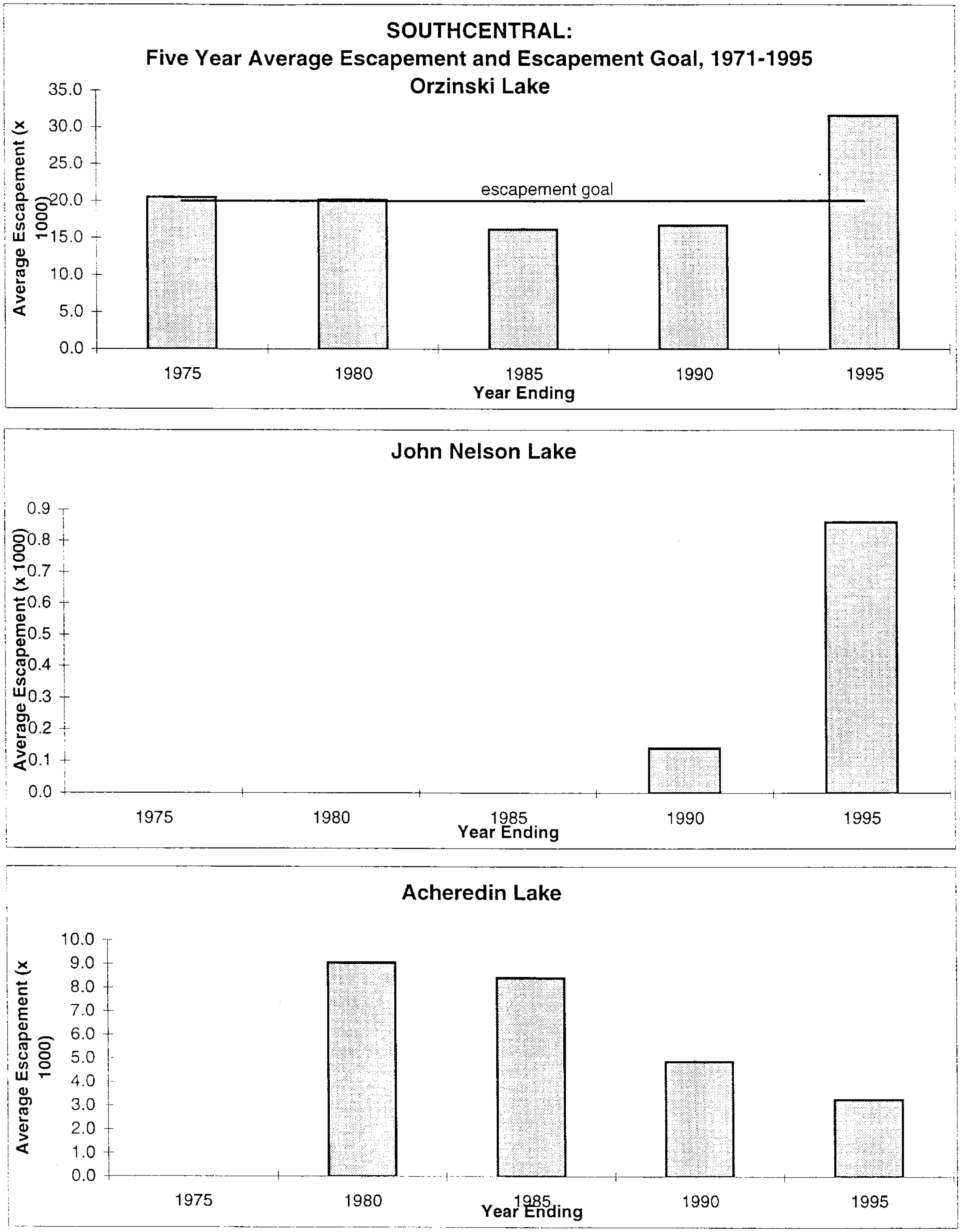
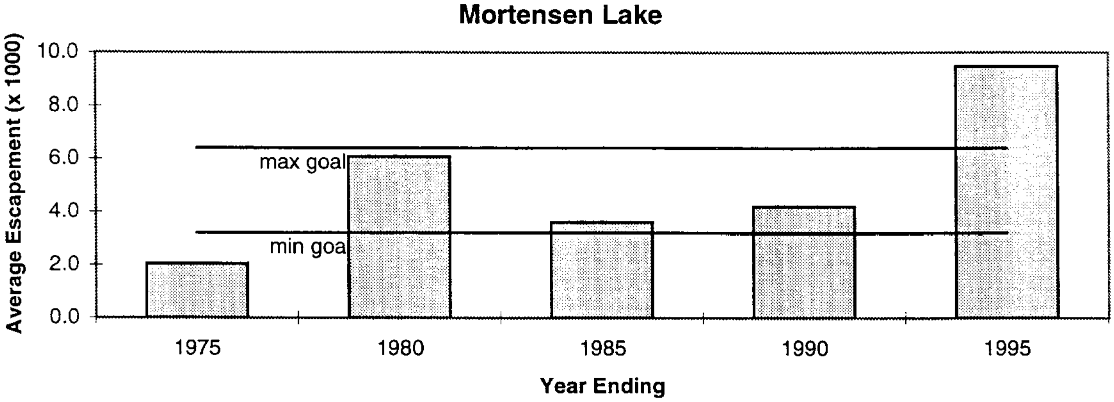
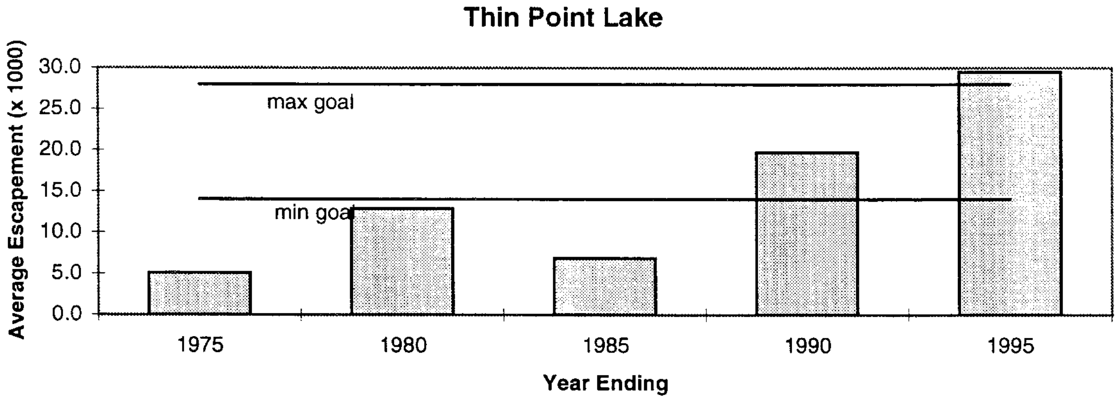


Figure 17. Five year average sockeye salmon escapement and the determined escapement goal, when available, for Orzinski, John Nelson, and Acheredin Lakes, 1971-1995.

COLD BAY: Large Systems
Five Year Average Escapement and Escapement Goals, 1971-1995





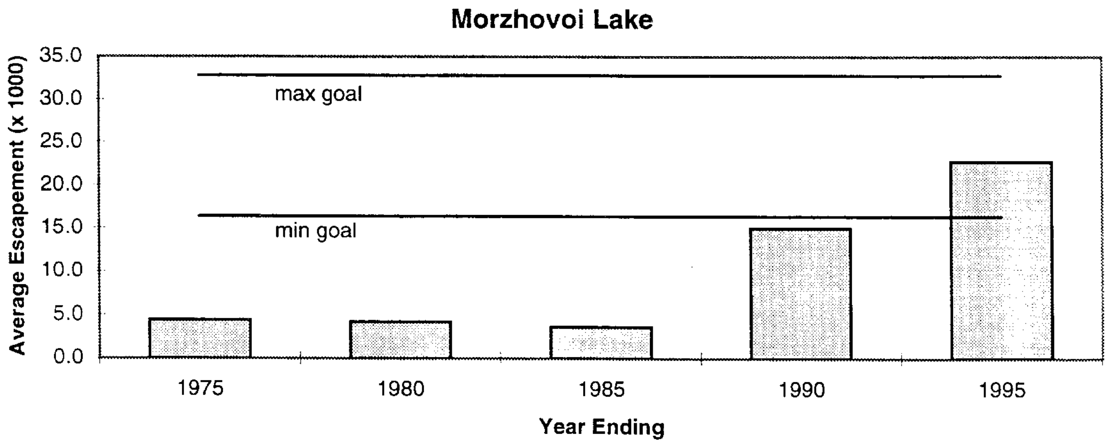
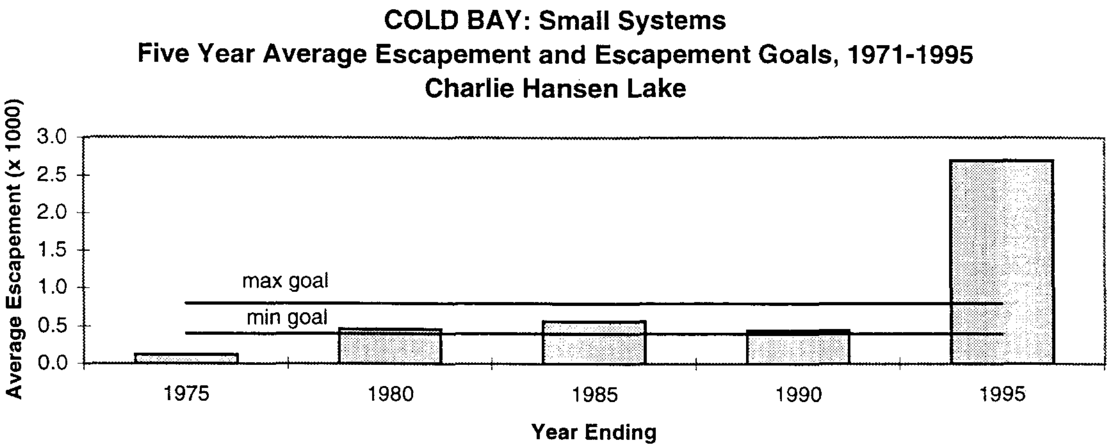


Figure 18. Five year average sockeye salmon escapement and the escapement goals for Mortensen, Thin Point, and Morzhovoi Lakes, 1971-1995.



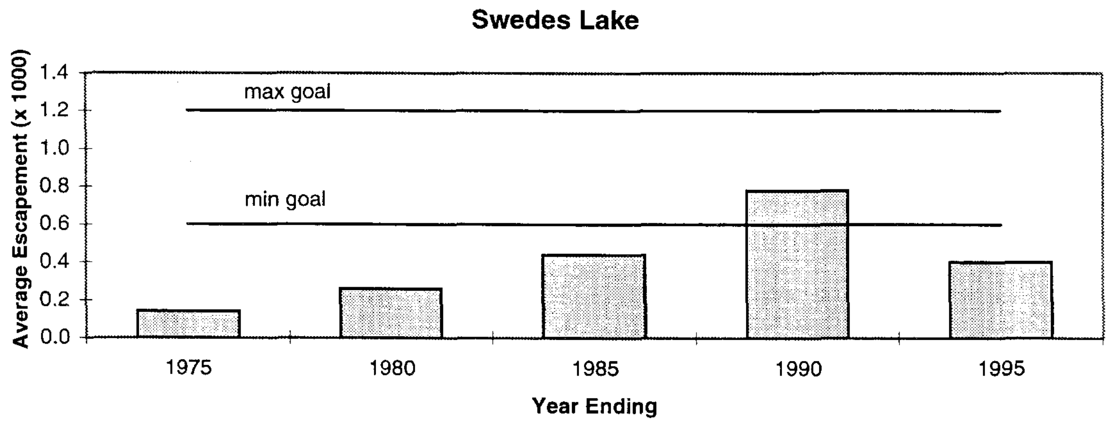


Figure 19. Five year average sockeye salmon escapement and the escapement goals for Charlie Hansen and Swedes Lakes, 1971-1995.

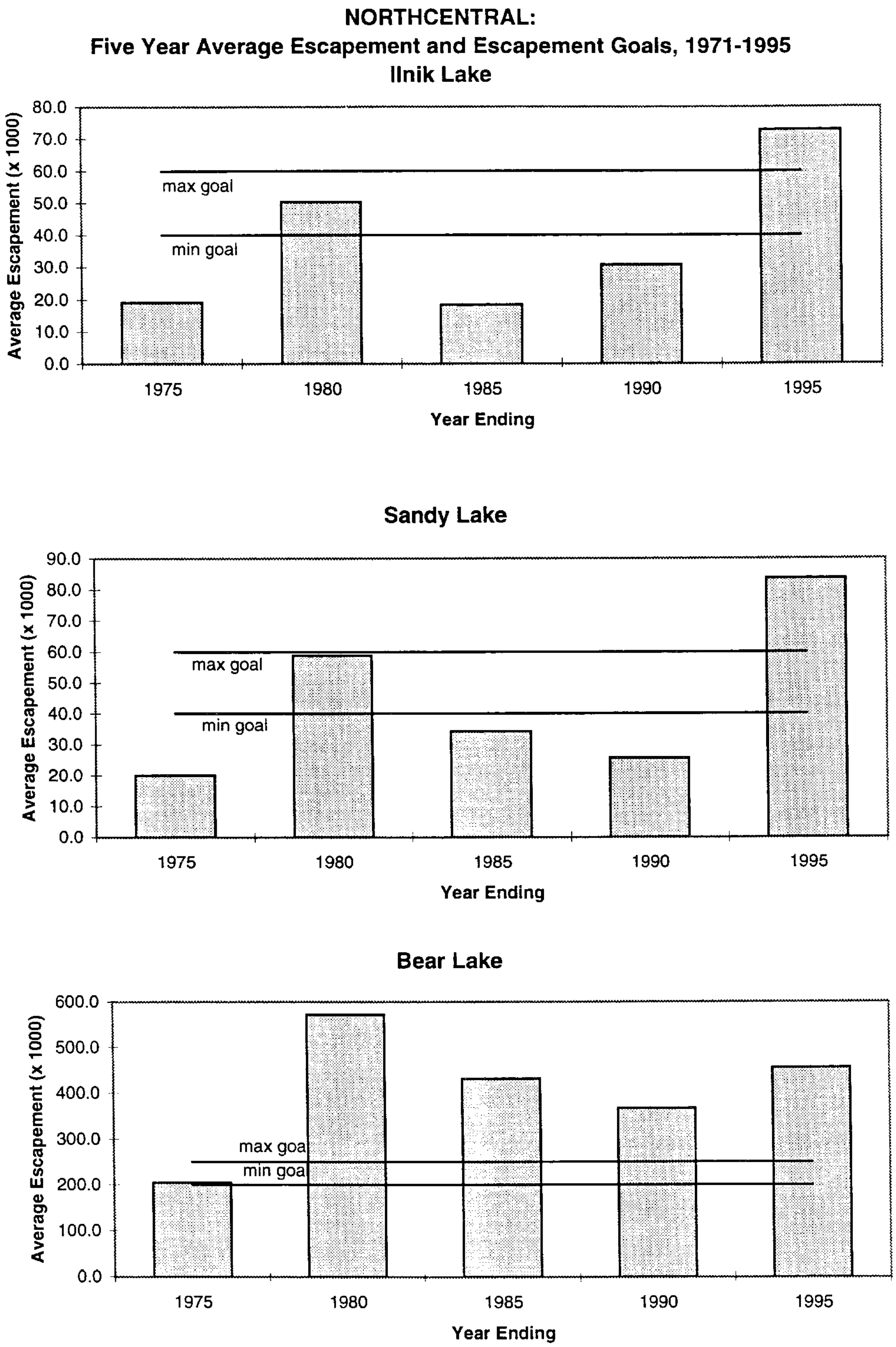
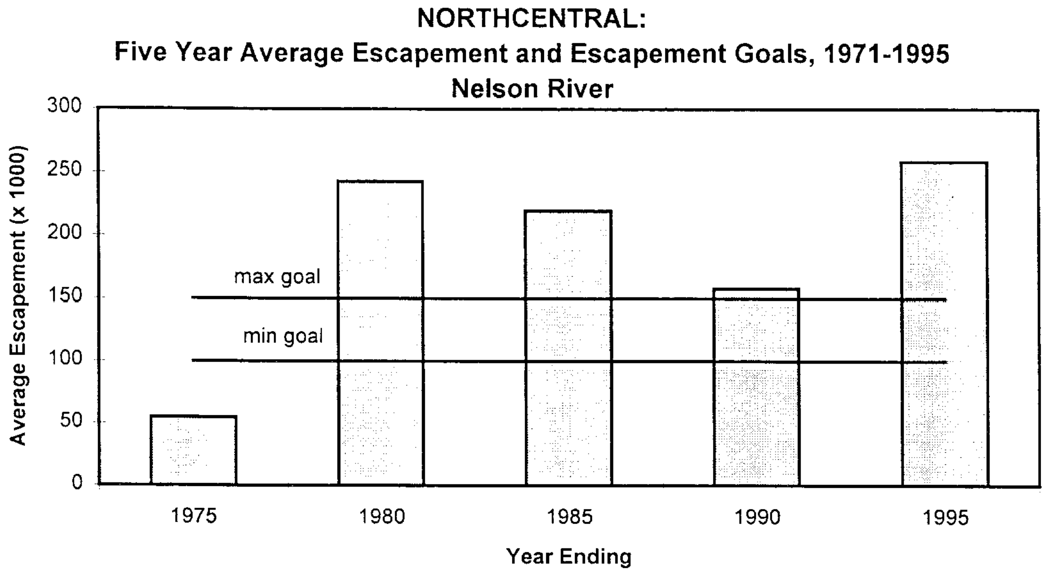
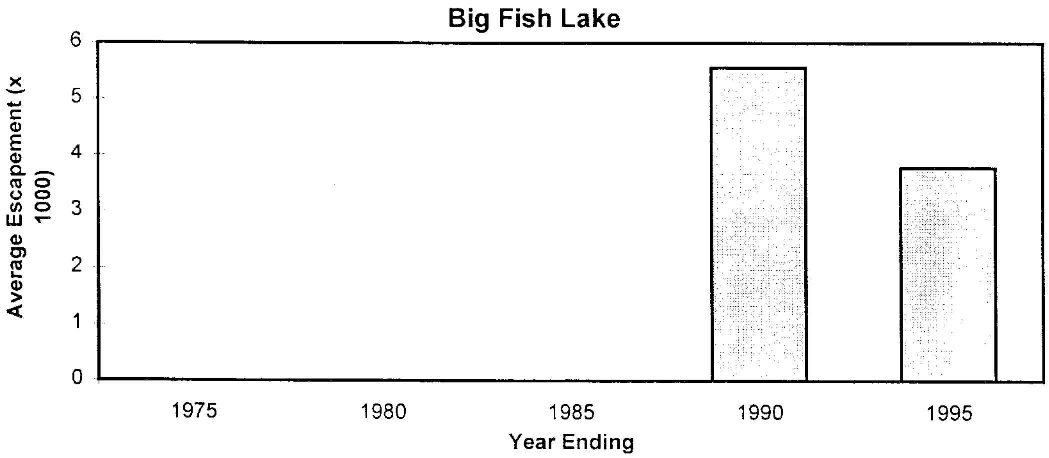


Figure 20. Five year average sockeye salmon escapement and the escapement goals for Ilnik Lake, Sandy Lake, and Bear Lake, 1971-1995.





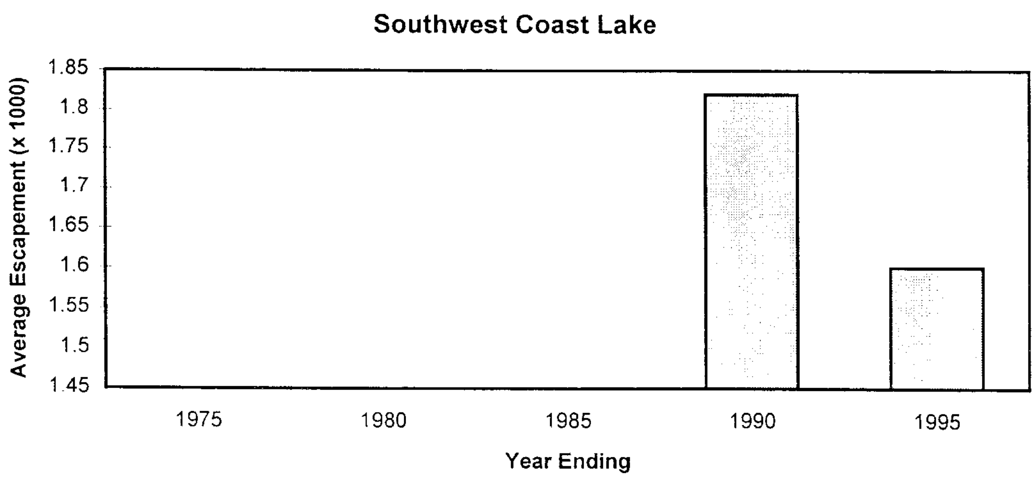


Figure 21. Five year average sockeye salmon escapement and the escapement goals, when available, for Nelson River, Big Fish, and Southwest Coast Lakes, 1971-1995.

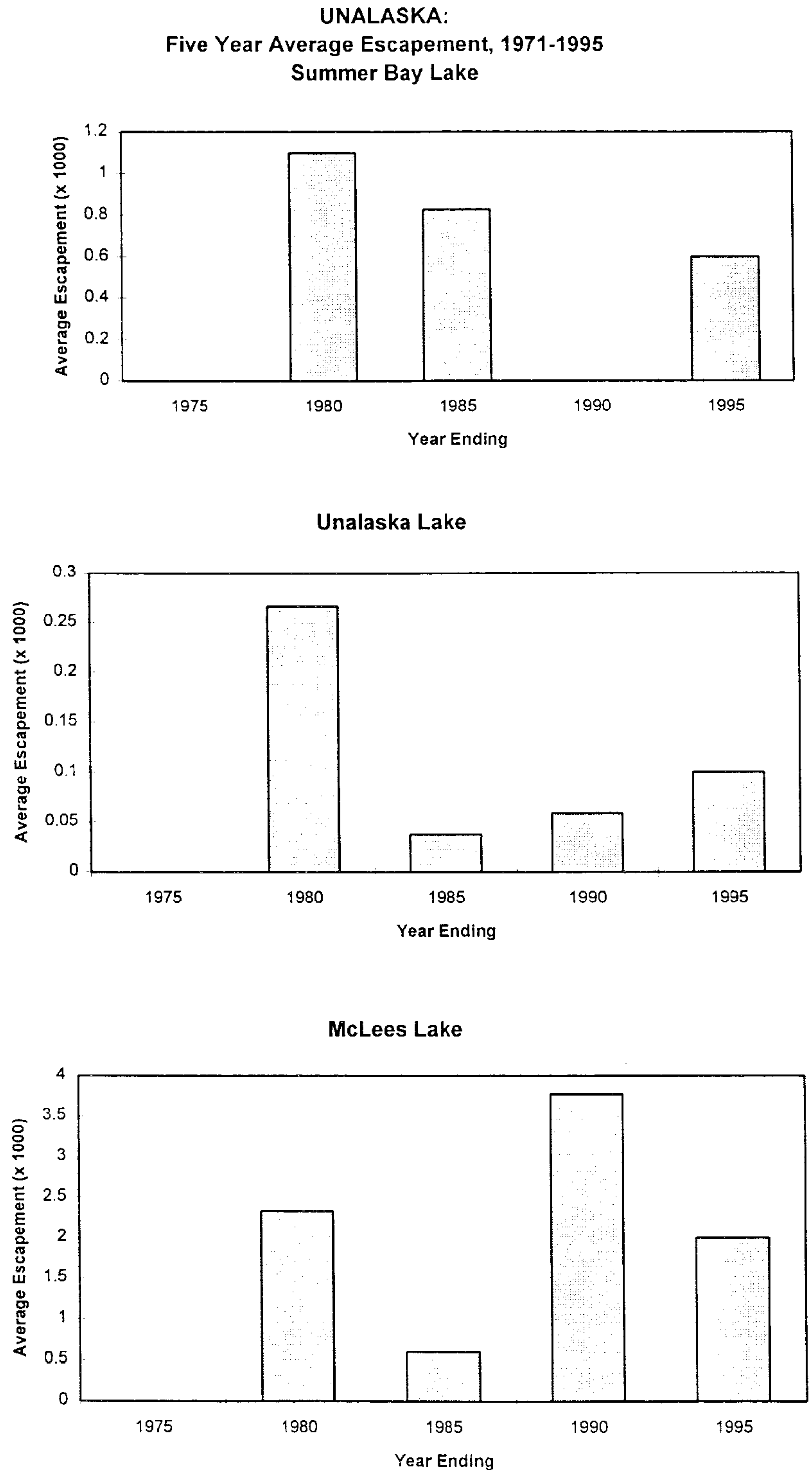
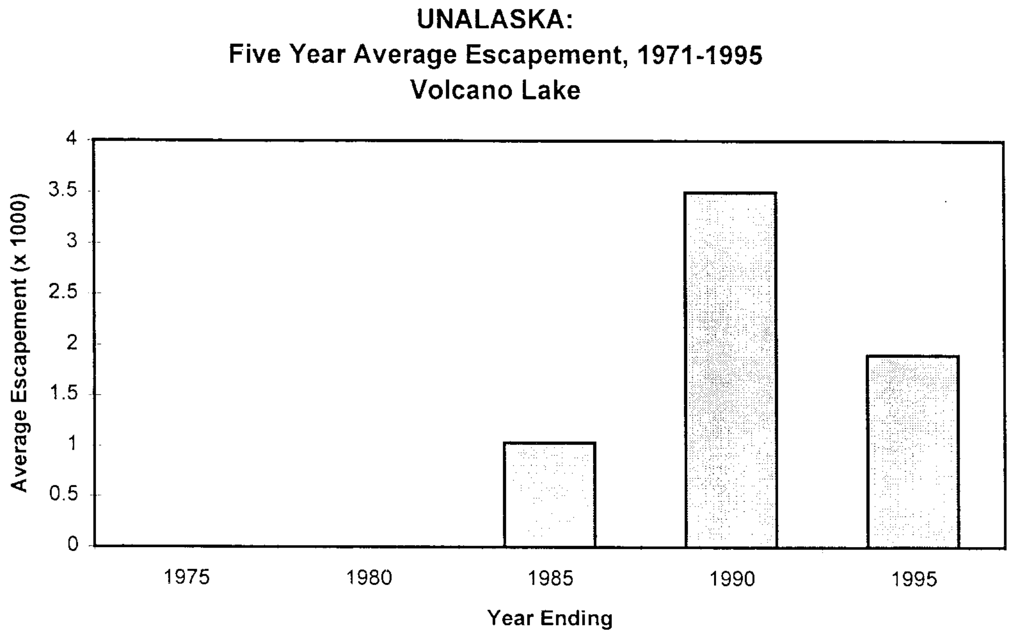


Figure 22. Five year average sockeye salmon escapement, when available, for Summer Bay, Unalaska, and McLees Lakes, 1971-1995.



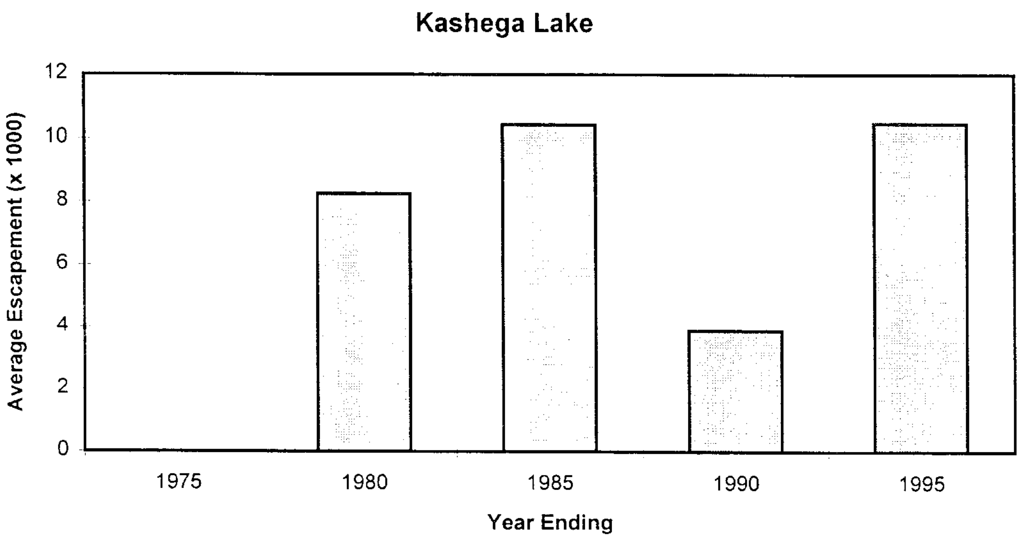
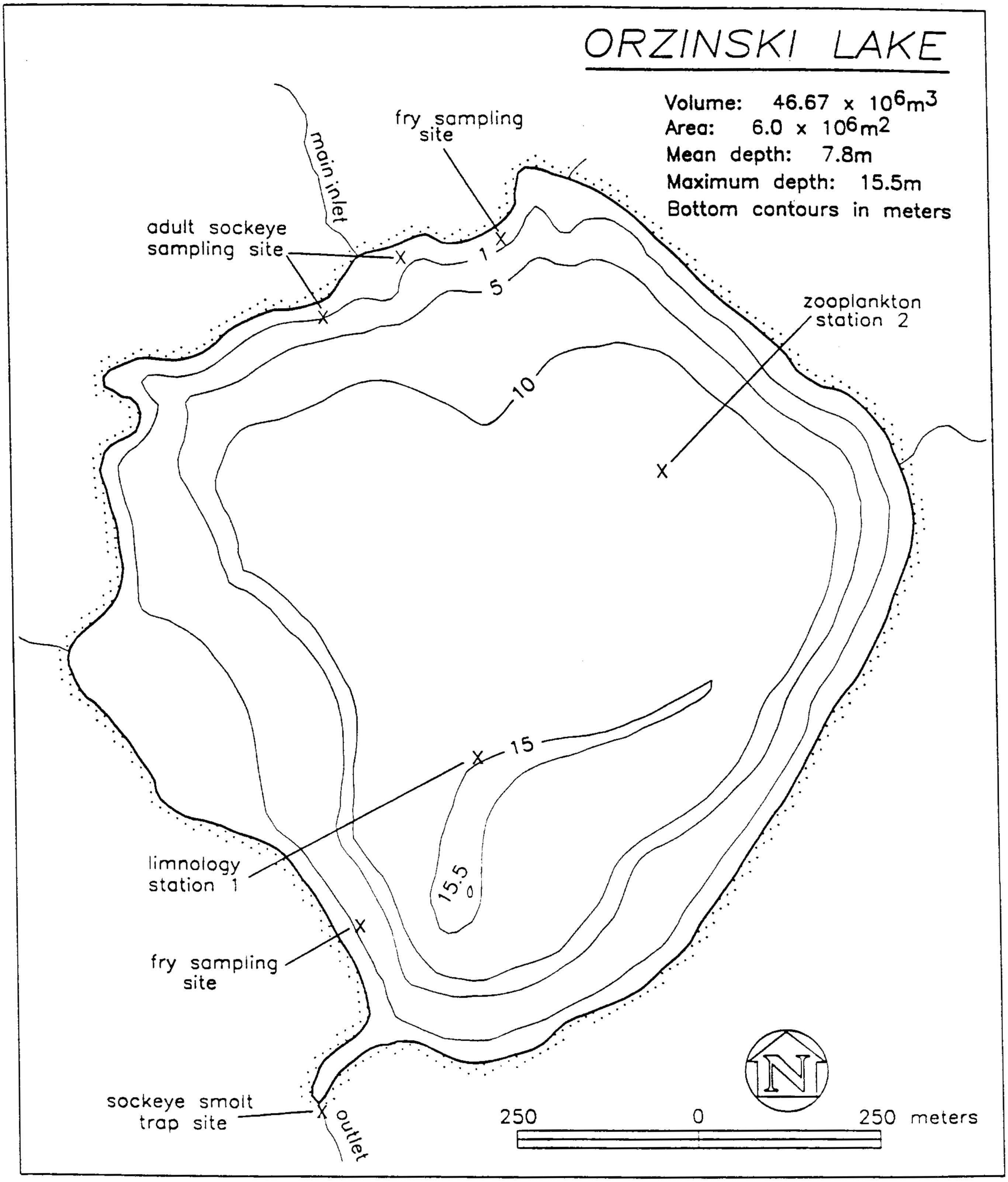
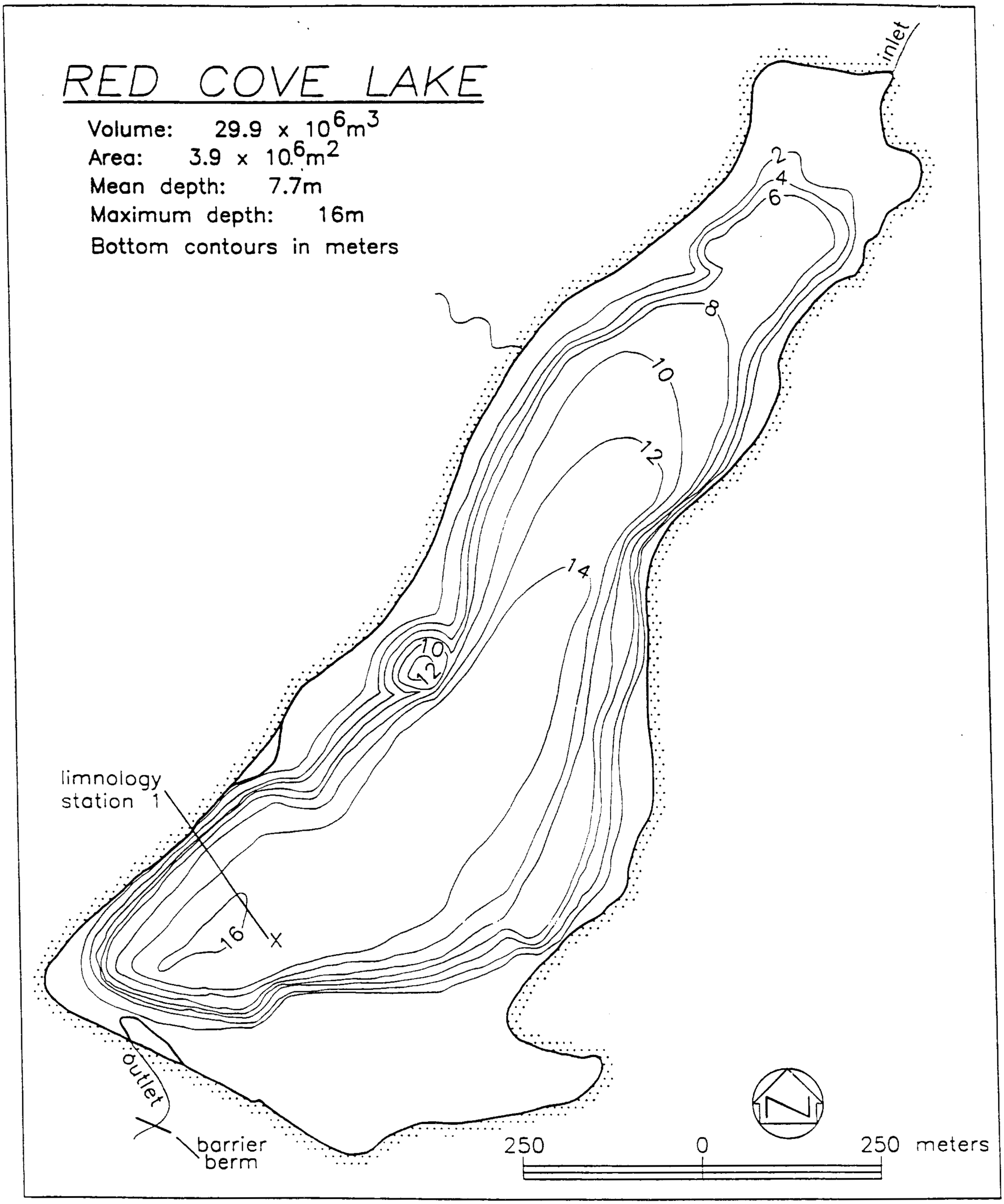


Figure 23. Five year average sockeye salmon escapement, when available, for Volcano and Kashega Lakes, 1971-1995.

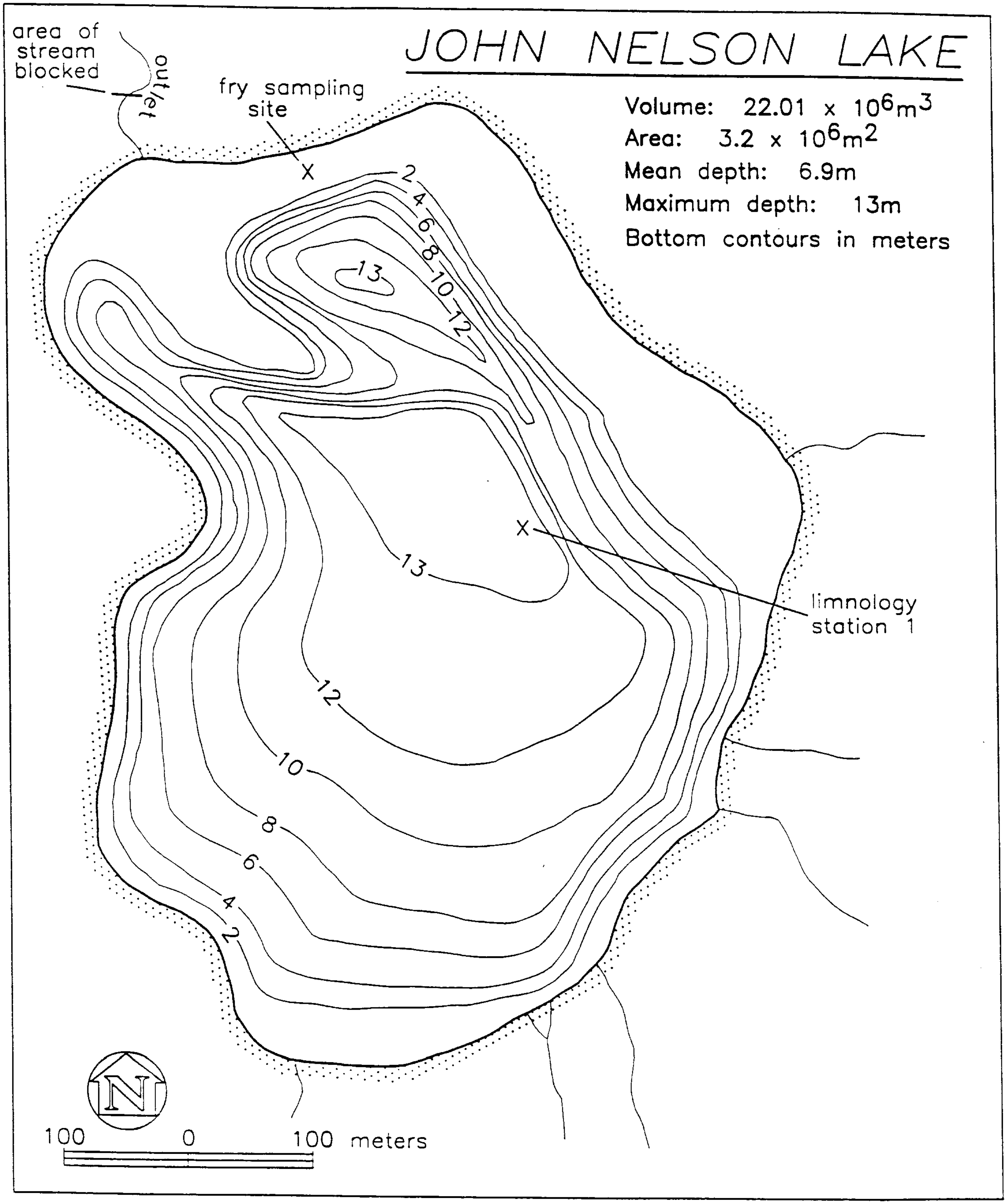
APPENDIX



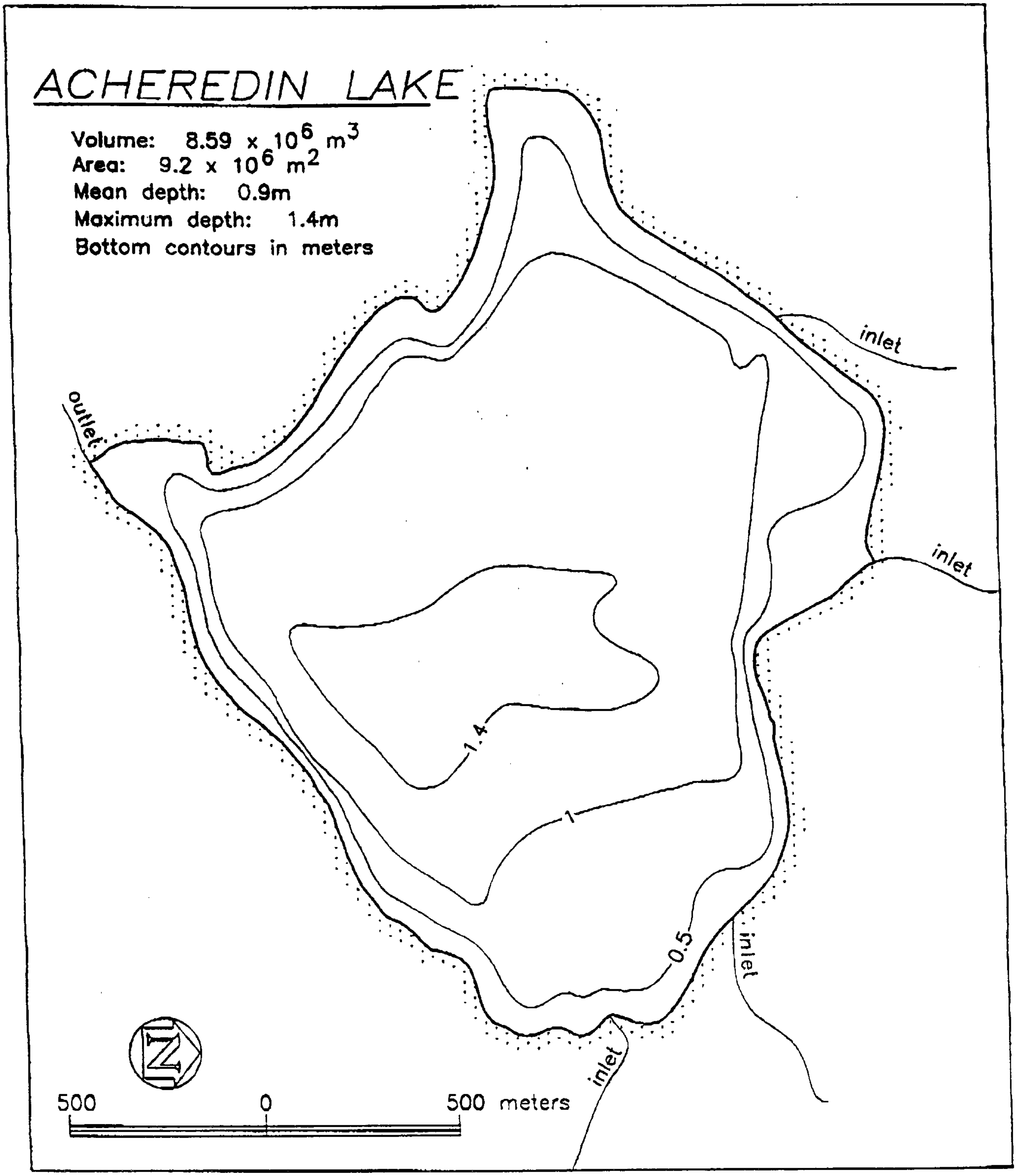
Morphometric map of Orzinski Lake (Orzenoi) showing the locations of the limnological and zooplankton sampling stations, beach seine sites for sockeye and coho fry sampling, sockeye smolt trap site, and beach seine site for adult sockeye desease screening.



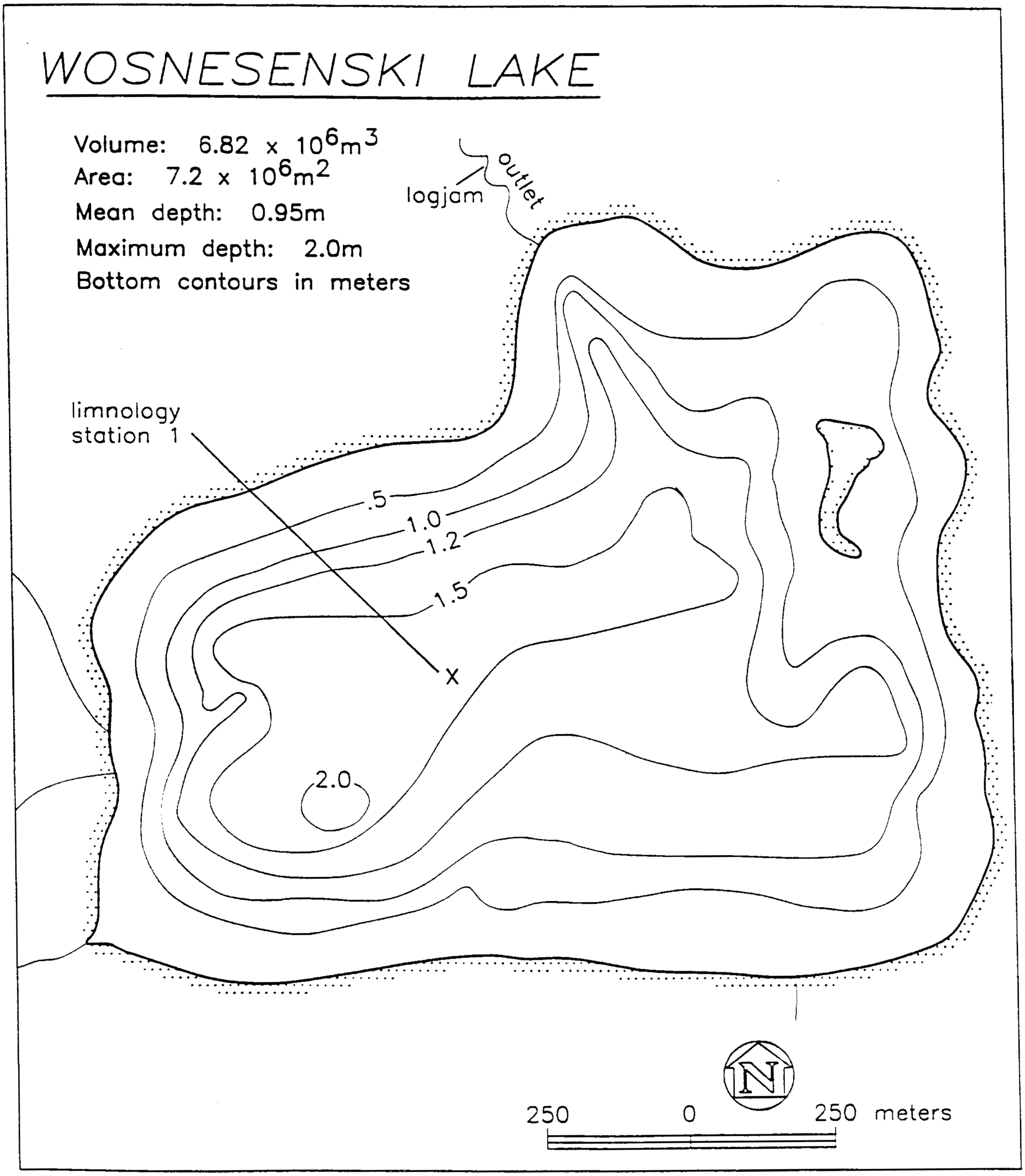
Morphometric map of Red Cove Lake showing the location of the limnological sampling station and barrier berm on the outlet stream.



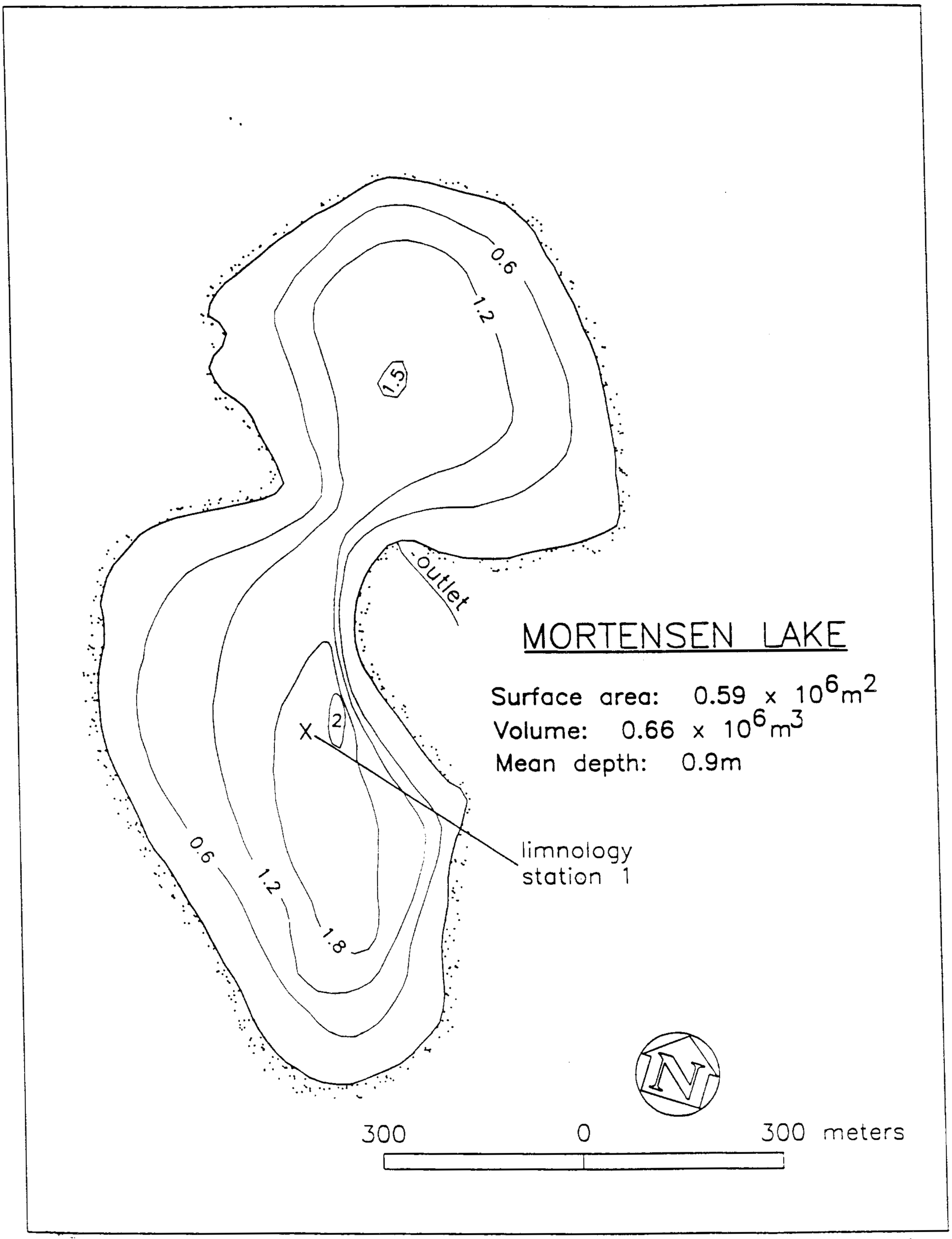
Morphometric map of John Nelson Lake showing the location of the limnological sampling station, fry sampling site, and area of debris blocking the outlet stream.



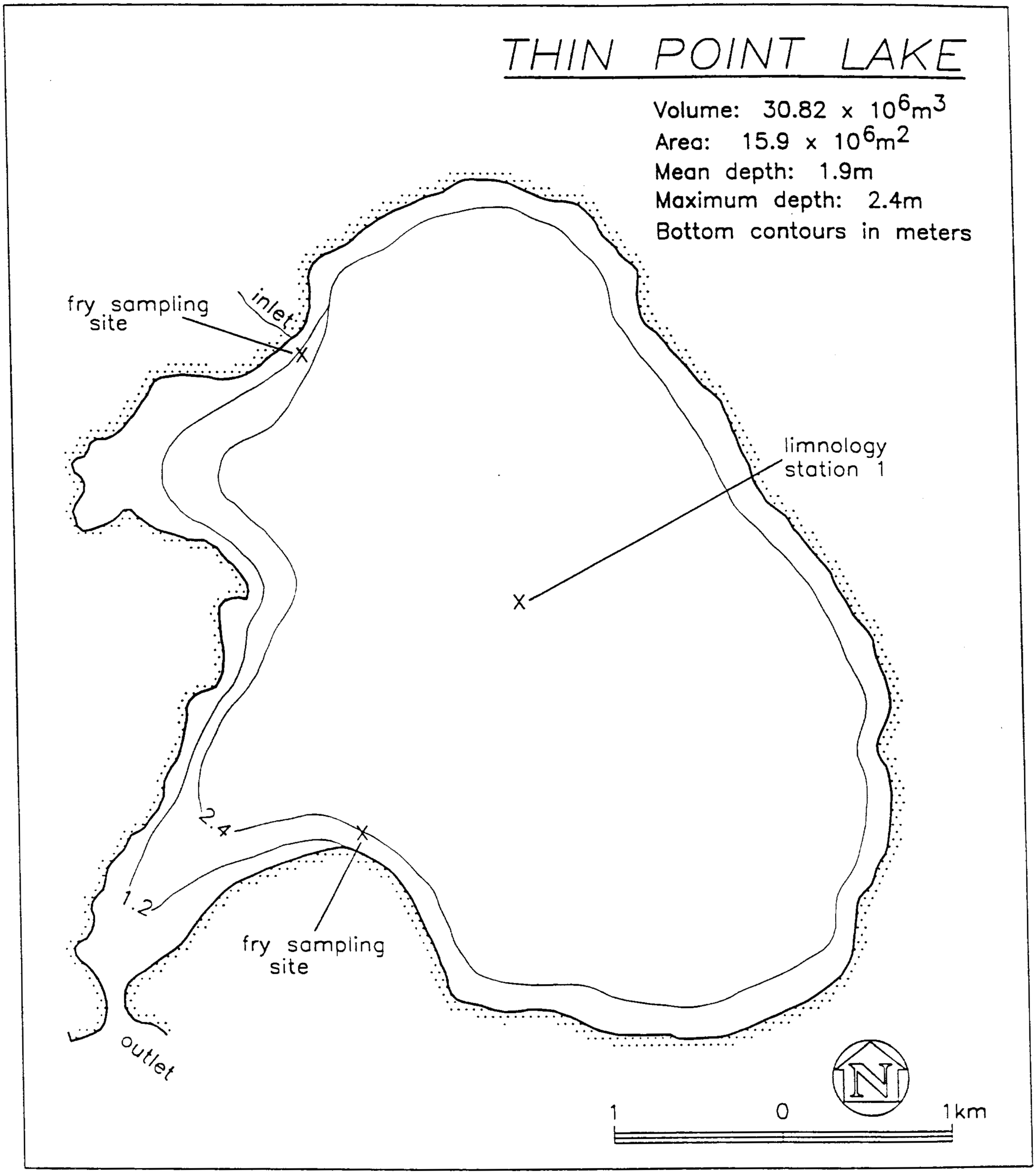
Morphometric map of Acheredin Lake showing the location of the limnological sampling station.



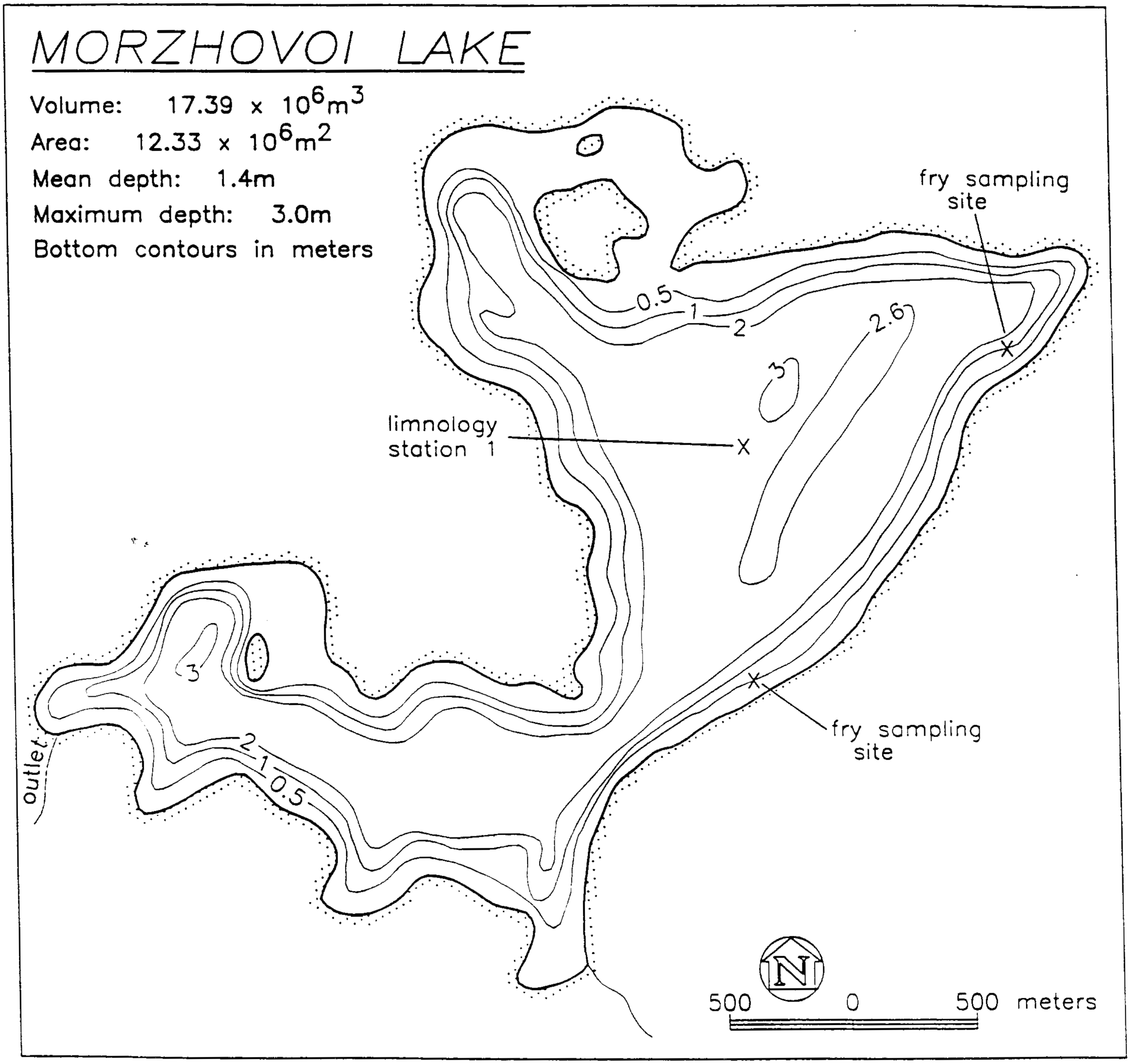
Morphometric map of Wosnesenski Lake showing the locations of the limnological sampling station, and the logjam on the outlet stream.



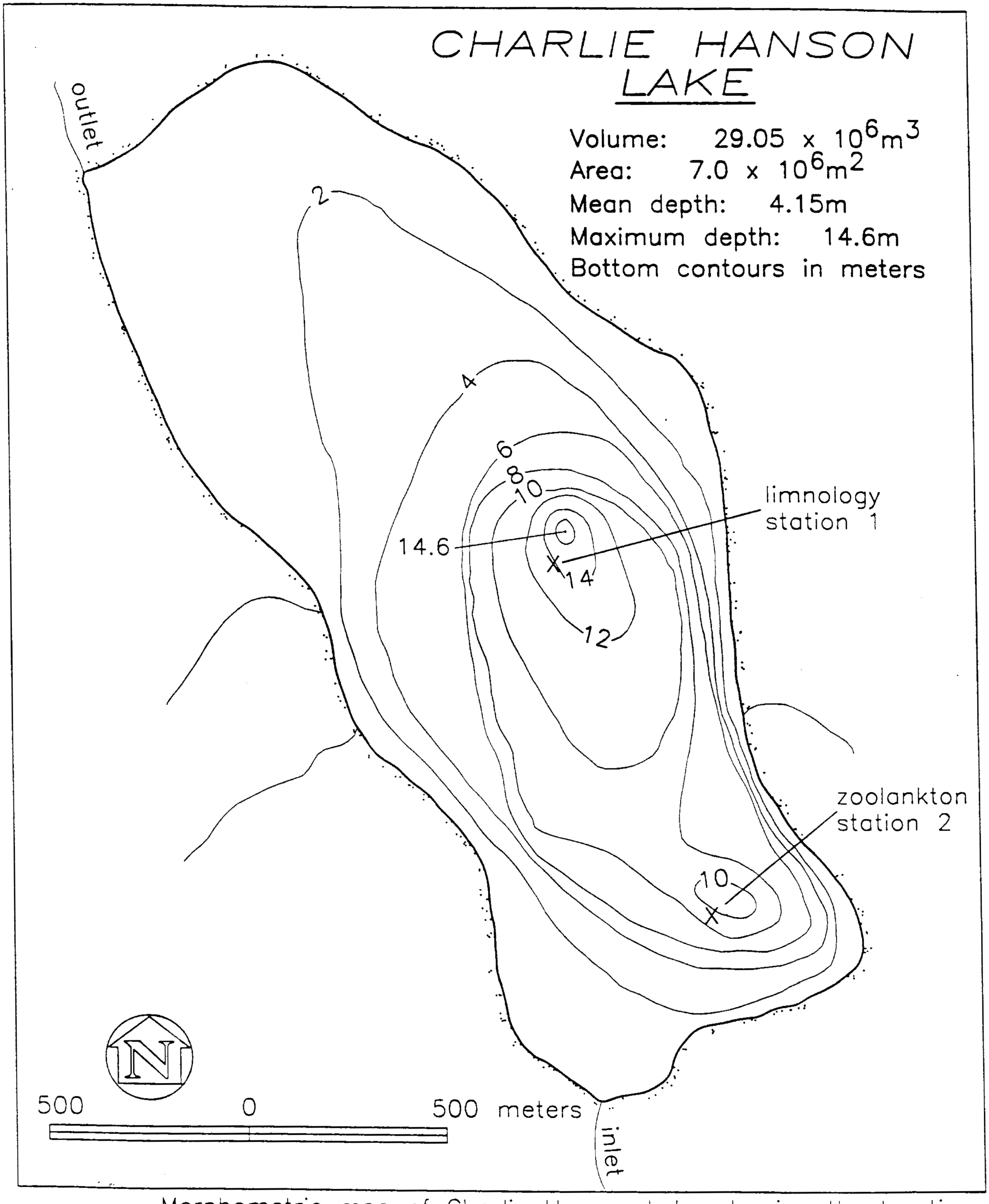
Morphometric map of Mortensen Lake showing the location of the limnological sampling station.



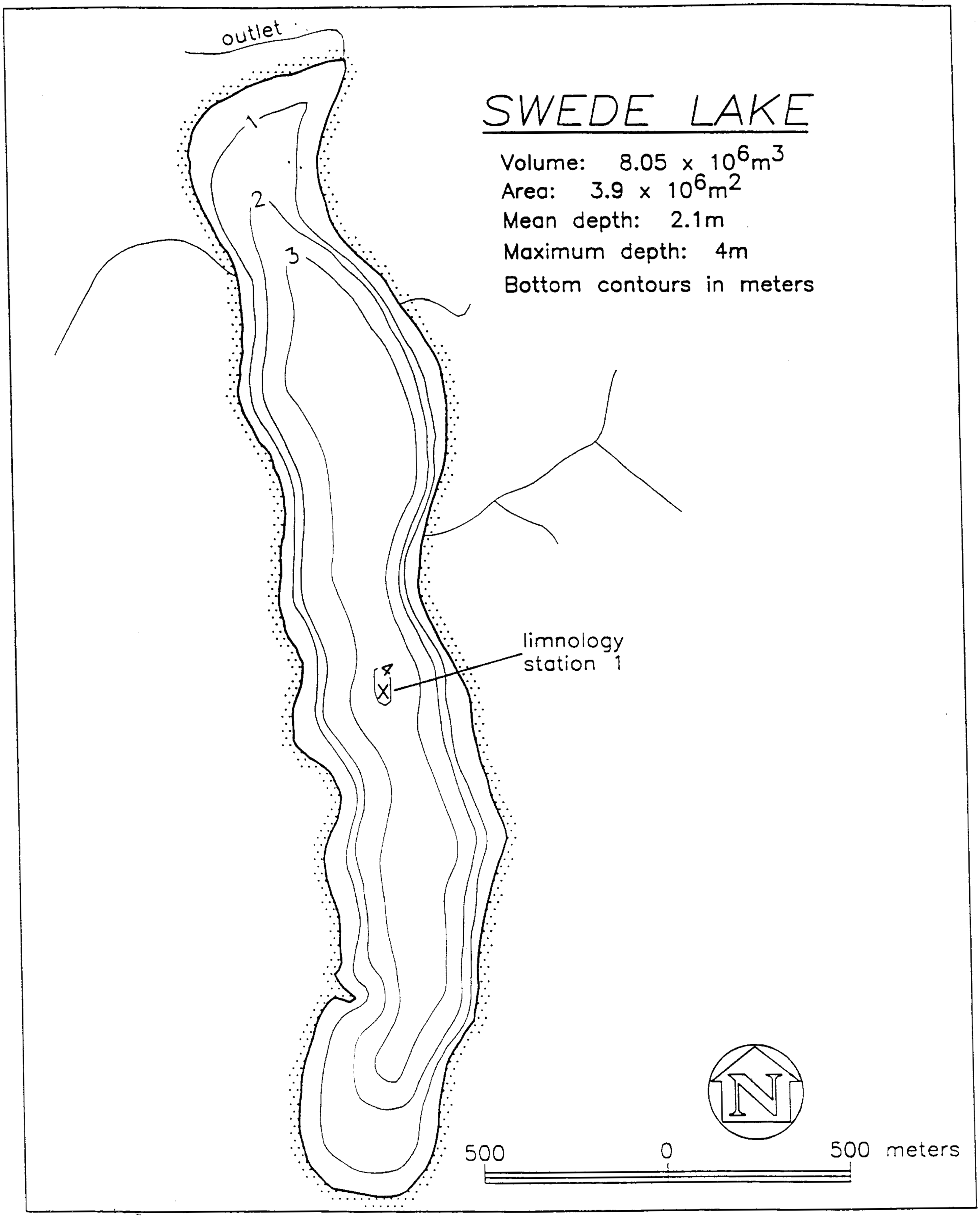
Morphometric map of Thin Point Lake showing the locations of the limnological sampling station, and beach seine sites for sockeye and coho fry sampling.



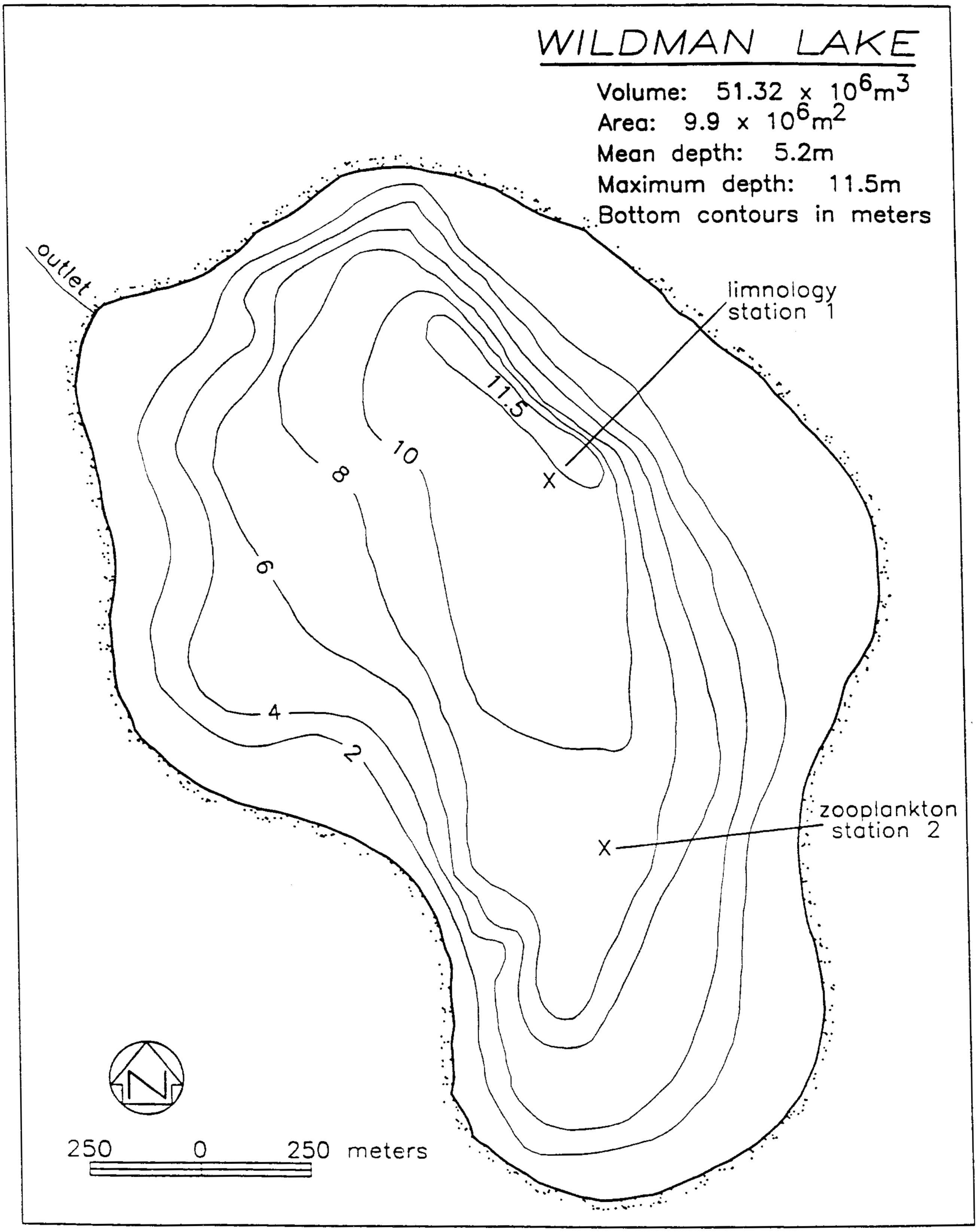
Morphometric map of Morzhovoi Lake showing the locations of the limnological sampling stations, and beach seine sites for sockeye and coho fry sampling.



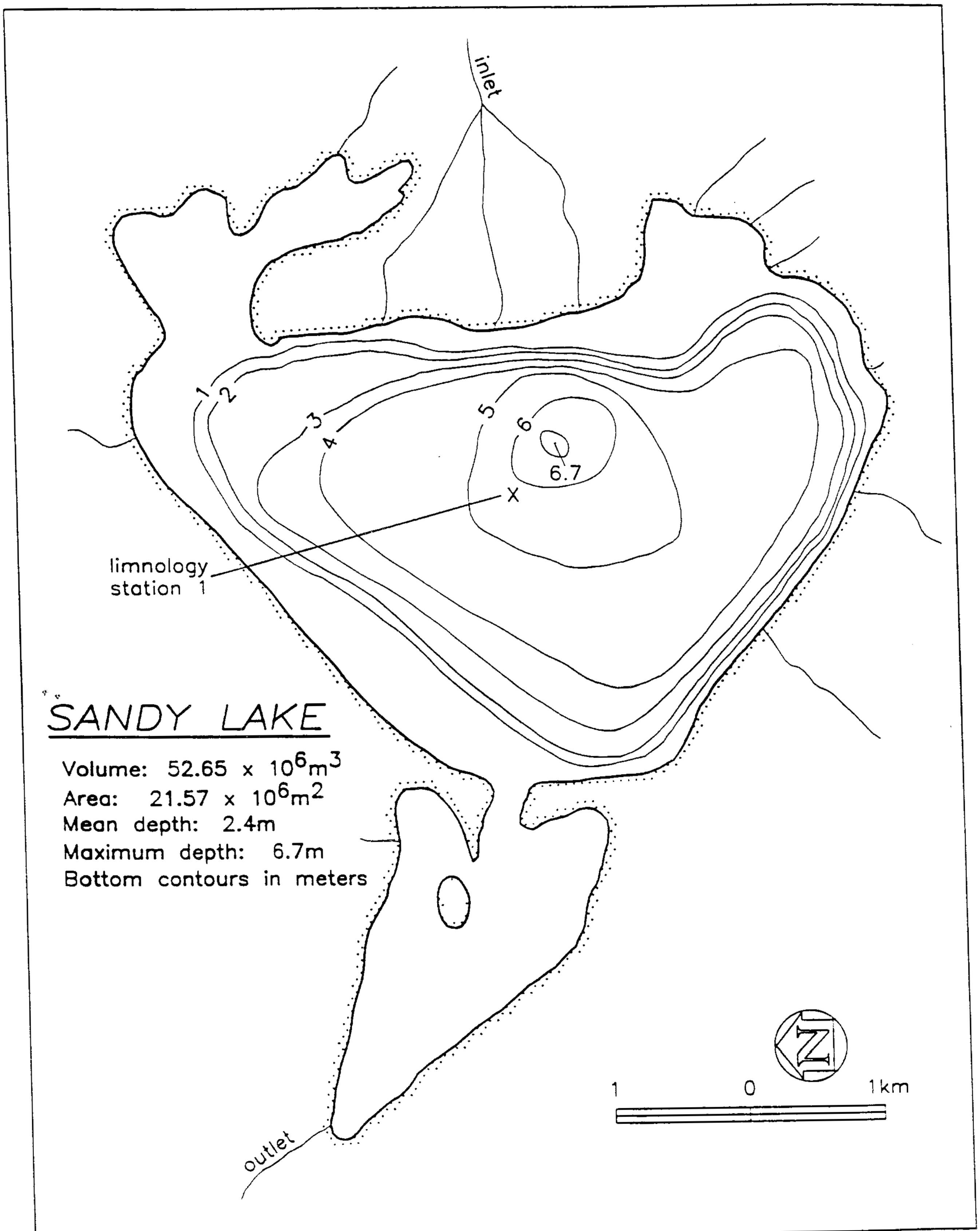
Morphometric map of Charlie Hansen Lake showing the locations of the limnological and zooplankton sampling stations.



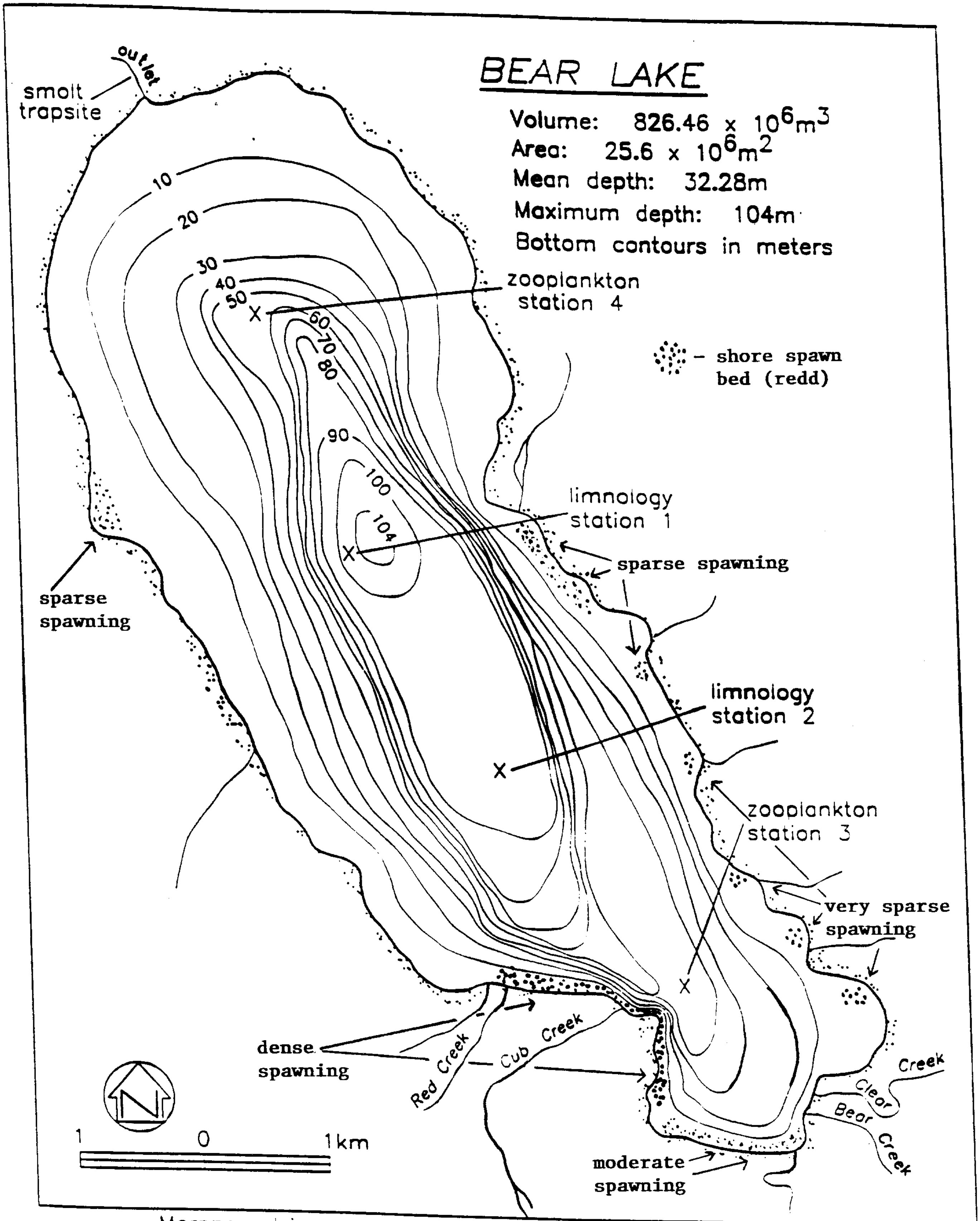
Morphometric map of Swede Lake showing the location of the limnological sampling station.



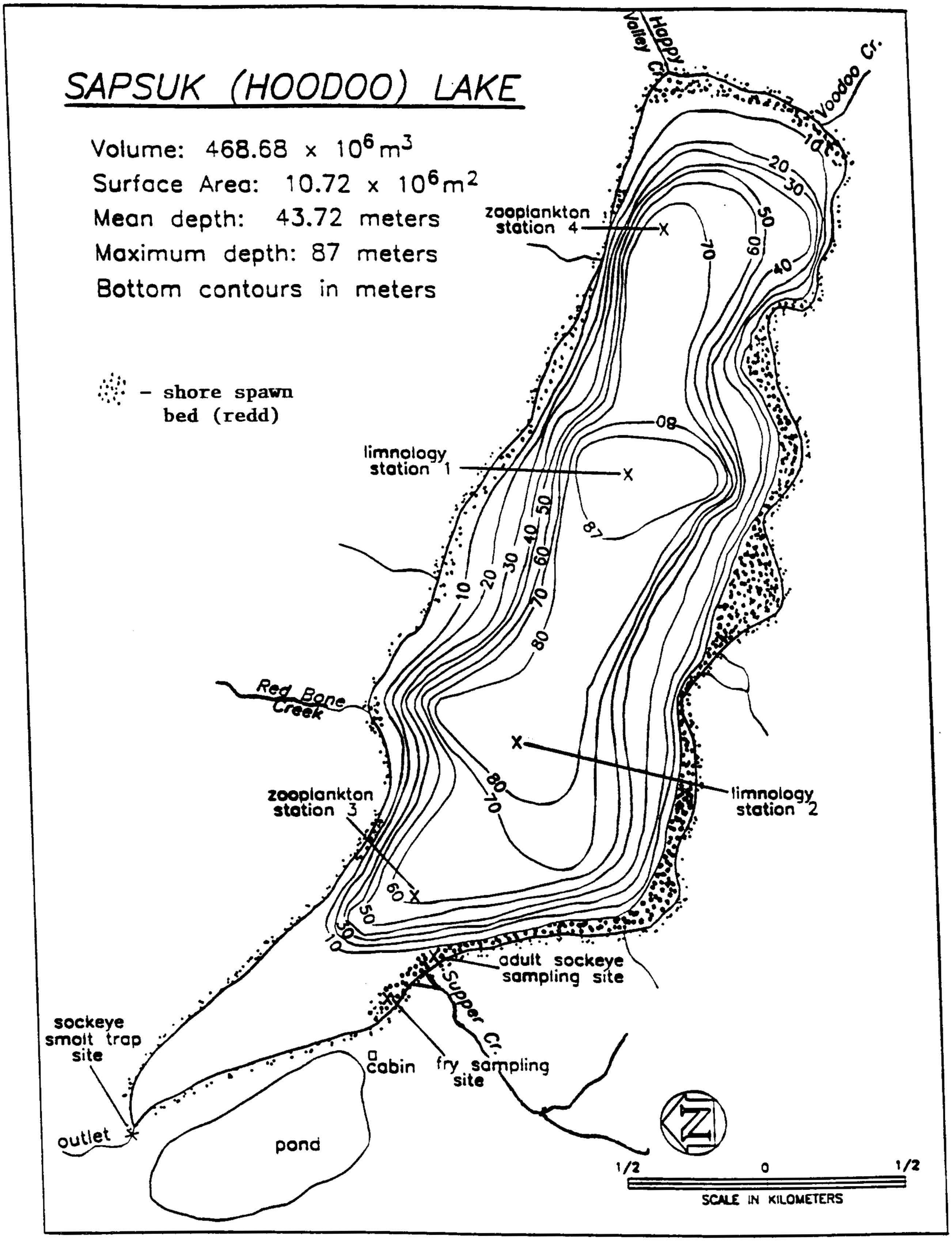
Morphometric map of Wildman Lake showing the locations of the limnological and zooplankton sampling stations.



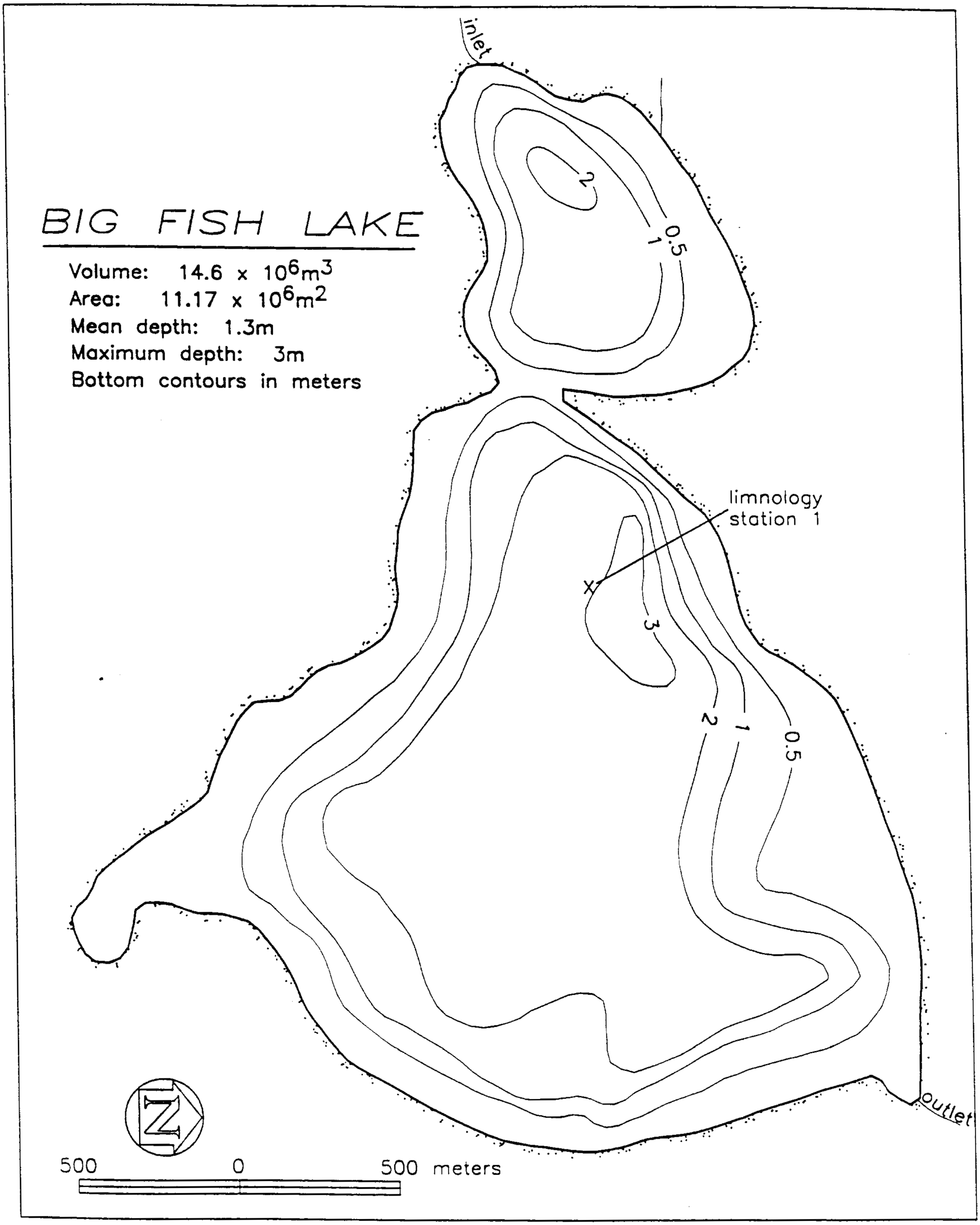
Morphometric map of Sandy Lake showing the location of the limnological sampling station.



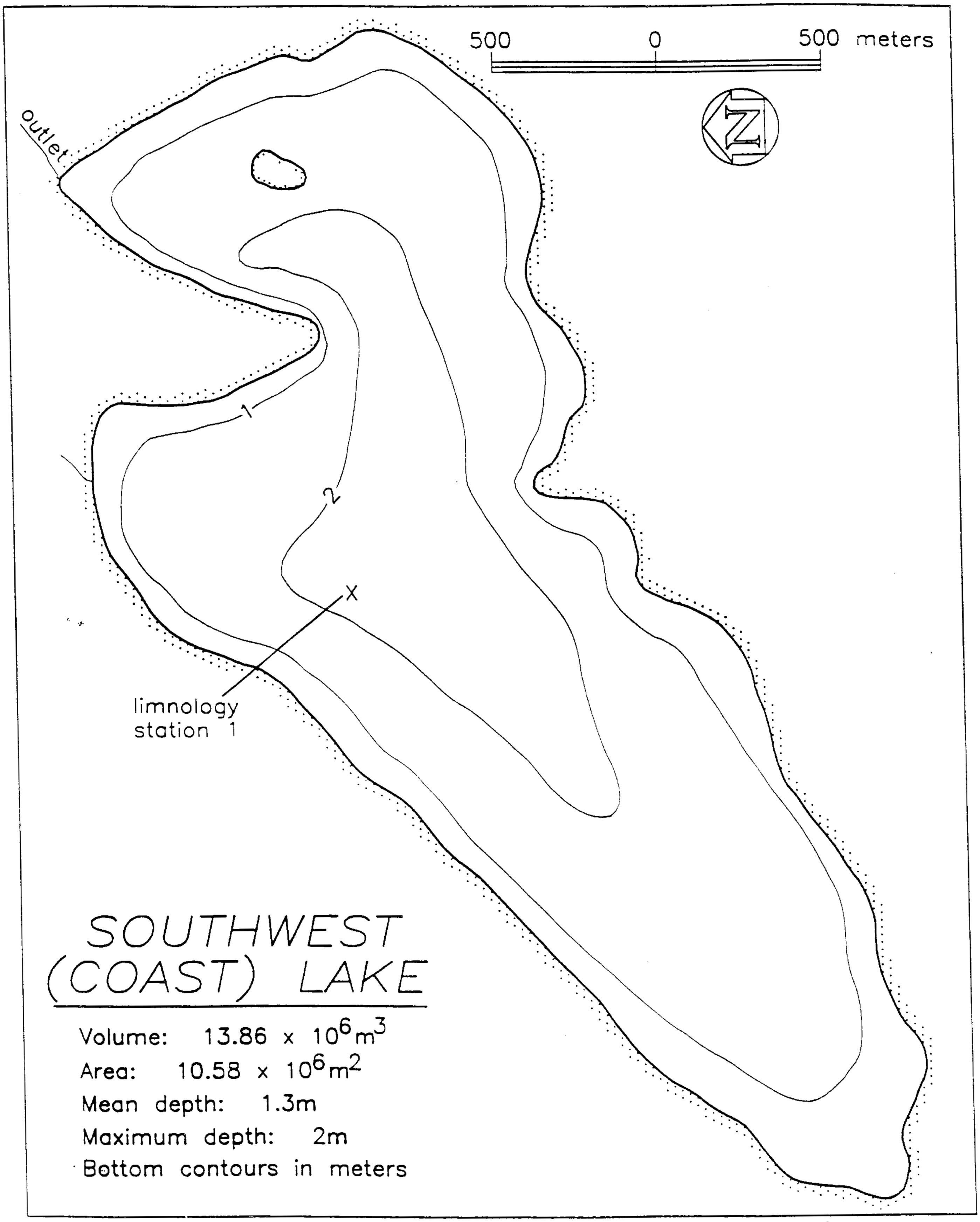
Morpnometric map of Bear Lake showing locations of the limnological and zooplankton sampling stations, and sockeye smolt trap site.



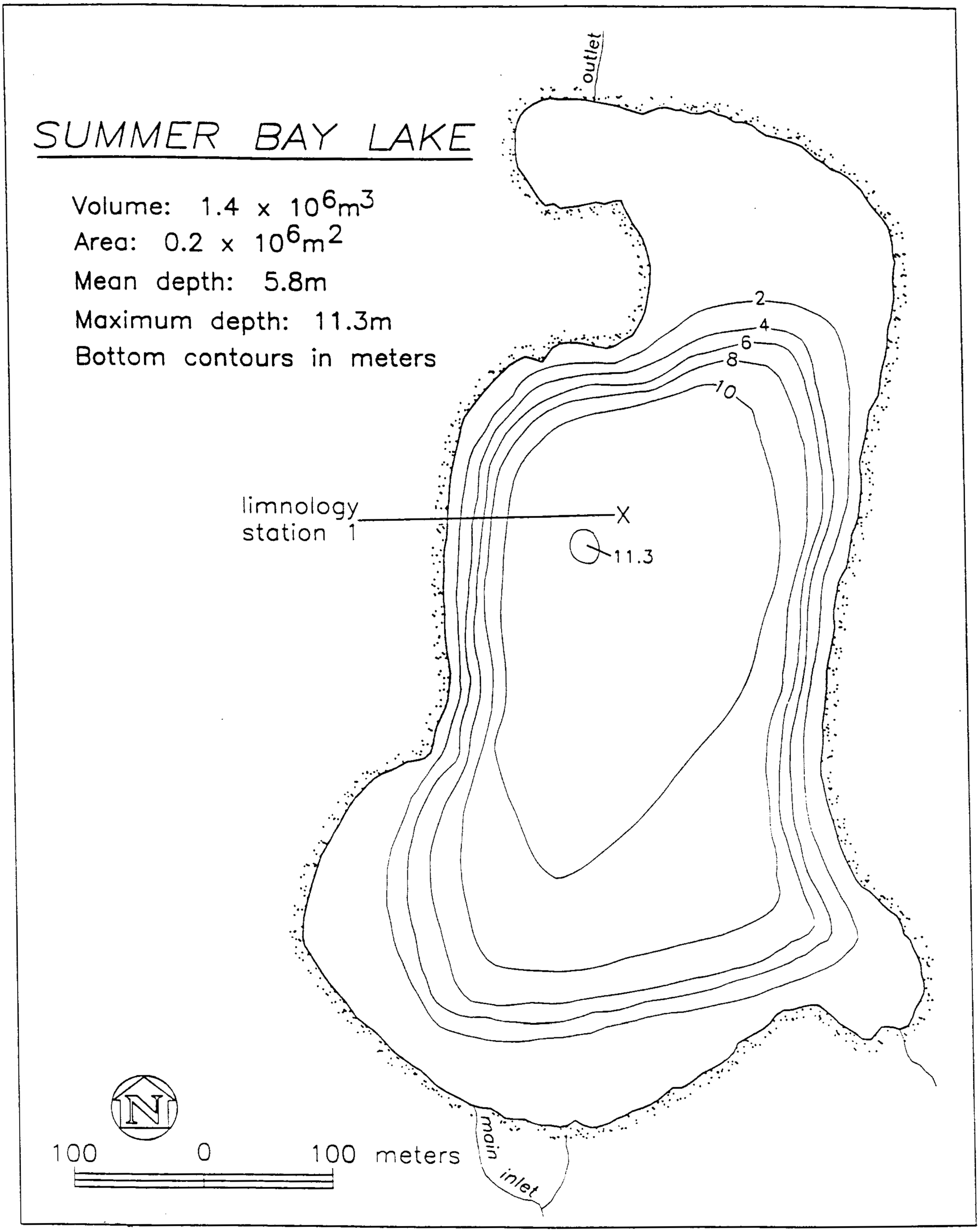
Morphometric map of Sapsuk Lake showing the locations of the limnological and zooplankton sampling stations, beach seine site for sockeye and coho fry sampling, beach seine site for adult sockeye disease screening, and sockeye smolt trap site.



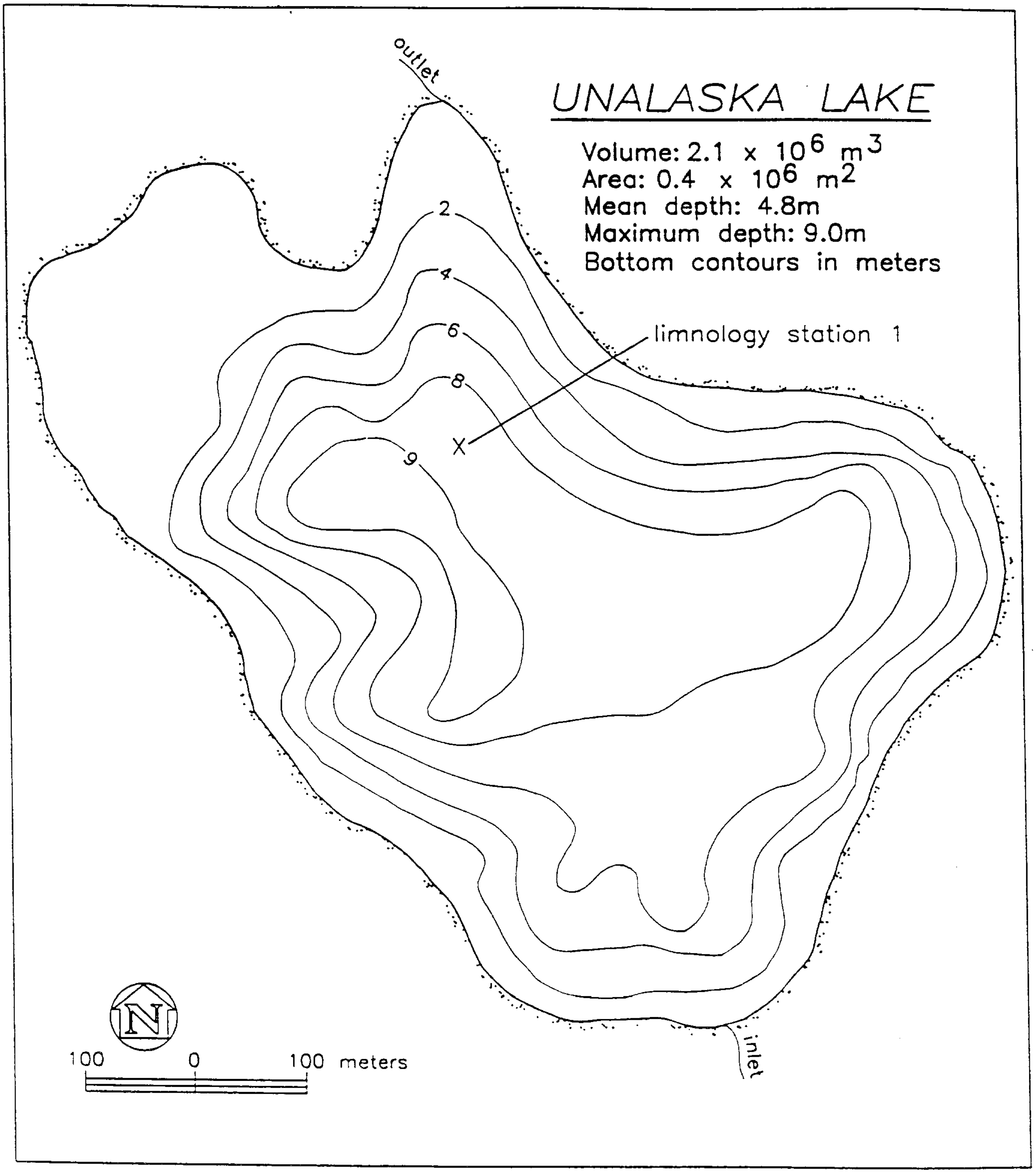
Morphometric map of Big Fish Lake showing the location of the limnological sampling station.



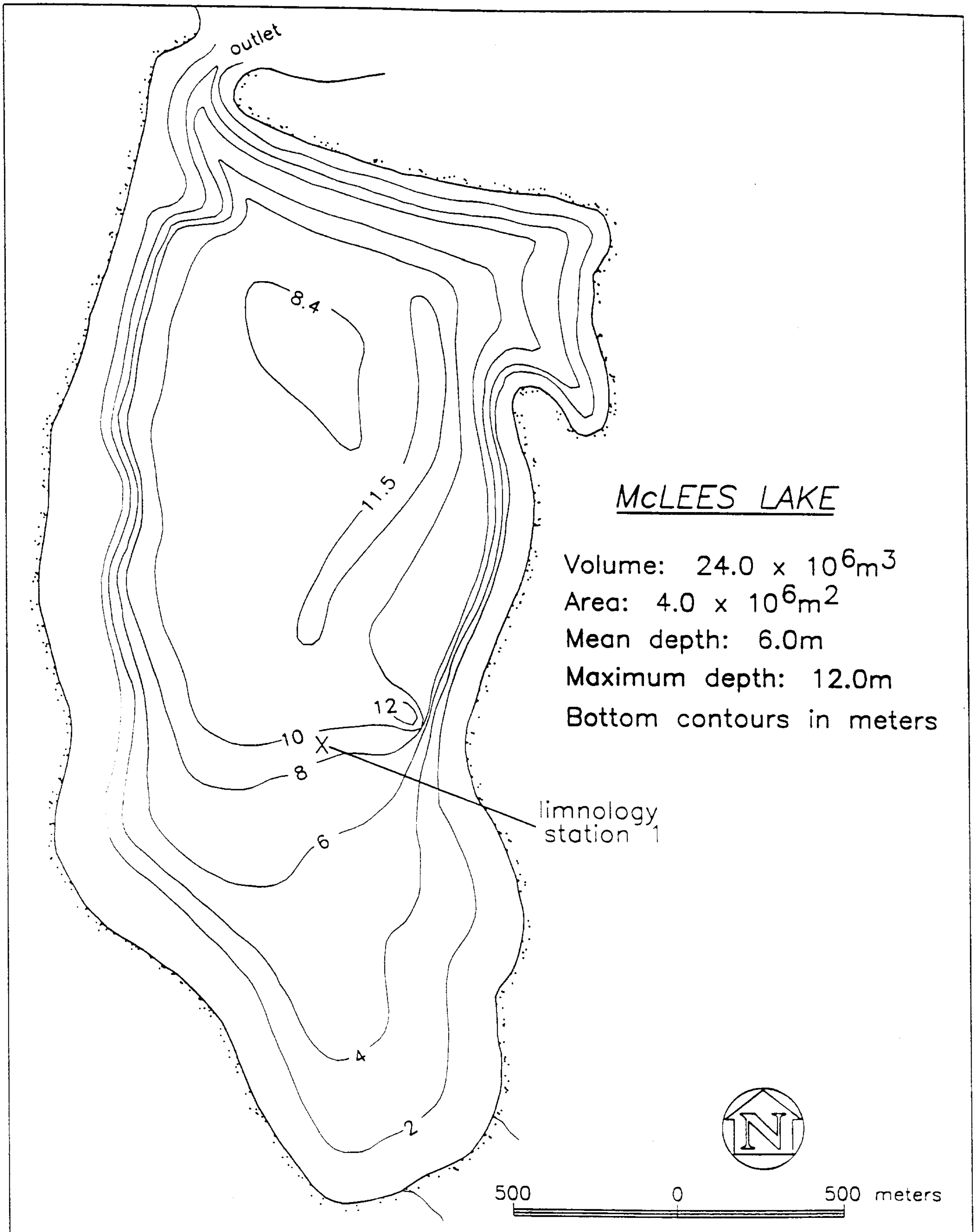
Morphometric map of Southwest (Coast) Lake showing the location of the limnological sampling station.



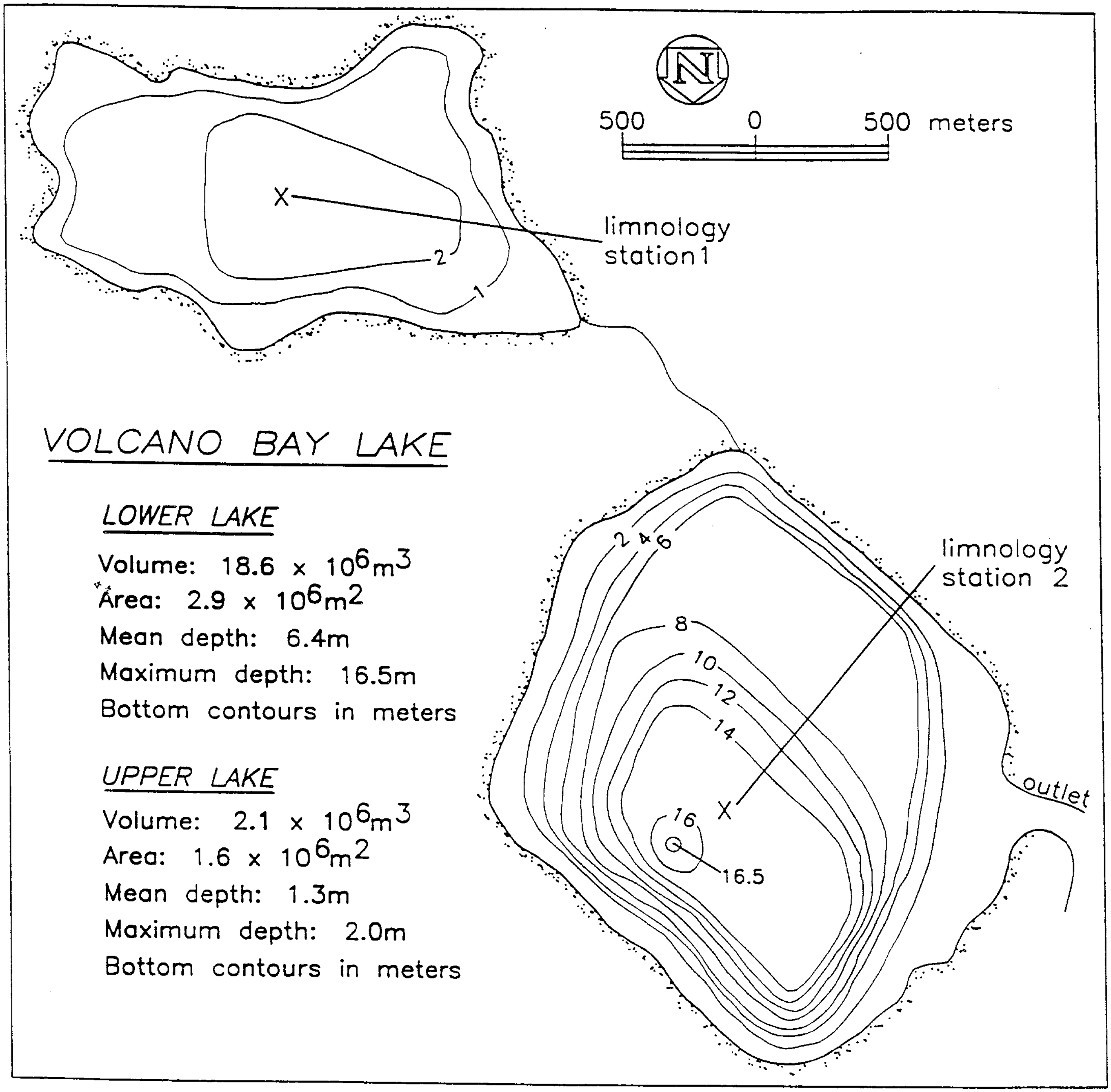
Morphometric map of Summer Bay Lake showing the location of the limnological sampling station.



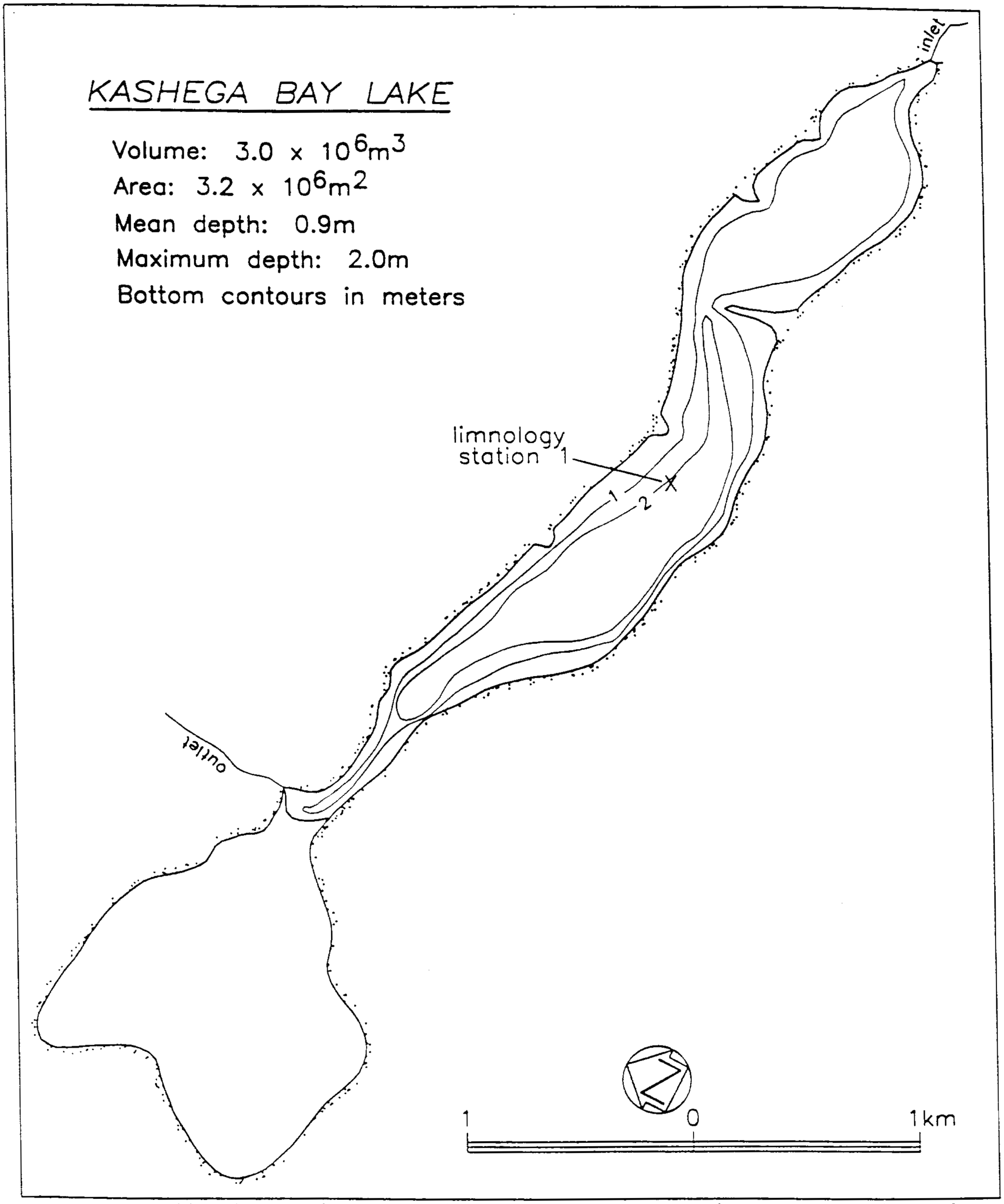
Morphometric map of Unalaska Lake showing the location of the limnological sampling station.



Morphometric map of McLees Lake showing the location of the limnological sampling station.



Morphometric map of Volcano Bay Lakes showing the location of the limnological sampling stations.



Morphometric map of Kashega Lake showing the location of the limnological sampling station.

Appendix B. Seasonal mean macrozooplankton density (D) (animals m^{-2}), biomass (B) (mg m^{-2}), and body size (S) (mm) by taxa for the Alaska Peninsula study lakes, 1993-1995.

SOUTHCENTRAL

Year	Taxa	Orzinski			Red Cove[4]			J. Nelson[4]			Acheredin			Wosnesenski		
		D	B	S	D	B	S	D	B	S	D	B	S	D	B	S
1993[1]	Bosmina	279	0.1	0.37							5	0.01	0.36			
	Cyclops	956	1	0.5							56	0.03	0.44			
	Eurytemora	52,827	258	0.9										3,006	4	0.68
	Harpacticoida	10,629	12	0.57										17	0.01	0.41
	Ergasilus				175	**[5]	**[5]	Not Sampled								
	Evadne[3]				122	**[5]	**[5]									
	Acartia[3]				25,919	**[5]	**[5]									
	TOTAL	**64,691**	**271.1**		**26,216**						**61**	**0.04**		**3,023**	**4.01**	
1994[2]	Bosmina	120	0.26	0.49							8	0.02	0.48	1,590	3.9	0.51
	Daphnia													8	0.01	0.54
	Chydorinae										72	0.3	0.7			
	Cyclops	624	0.45	0.49							1,624	1.3	0.5	566	1.4	0.82
	Eurytemora	60,938	189	0.68	239	**[5]	**[5]				438	1.4	0.68	1,359	3.02	0.55
	Harpacticoida													16	0.01	0.41
	Macrothricidae										159	0.1	0.38			
	Evadne[3]				319	**[5]	**[5]	108,564	**[5]	**[5]						
	Podon[3]							2,795	**[5]	**[5]						
	Acartia[3]				52,468	**[5]	**[5]	133,935	**[5]	**[5]						
	Ergasilus				239	**[5]	**[5]									
	TOTAL	**61,682**	**189.71**		**53,265**			**245,294**			**2,301**	**3**		**3,539**	**8.34**	
1995[2]	Bosmina	666	1.3	0.43	Not Sampled			Not Sampled			Not Sampled			Not Sampled		
	Daphnia	36	0.1	0.8												
	Cyclops	345	0.35	0.54												
	Eurytemora	87,254	300	0.73												
	TOTAL	**88,301**	**301.75**													
	Mean '93-'94	**63,187**	**230**		**39,741**						**1,181**			**3,281**	**6**	
	Mean '94-'95	**74,992**	**246**													
	Mean '93-'95	**71,558**	**254**													

-Continued-

COLD BAY

Year	Taxa	Mortensen			Thin Point			Morzhovoi			C. Hansen			Swede		
		D	B	S	D	B	S	D	B	S	D	B	S	D	B	S
1993[1]	Bosmina				24	0.04	0.41				54,565	55	0.33	431	0.52	0.37
	Chydorinae										956	2	0.47	8	0.03	0.6
	Cyclops				96	0.19	0.76	9,342	11	0.59	2,482	2	0.51	2,001	1.24	0.44
	Eurytemora				24	0.05	0.75	12,049	81	1.09				69	0.27	0.78
	Harpacticoida	Not Sampled												27	0.01	0.34
	Ergasilus				16	0.02	0.67									
	Macrothricidae										40	0.03	0.4	53	0.04	0.42
	Heterocope										40	0.3	1.06			
	TOTAL				**160**	**0.3**		**21,391**	**92**		**58,083**	**59.33**		**2,589**	**2.11**	
1994[2]	Bosmina	88	0.22	0.48	32	0.04	0.36	637	1.28	0.49	41,877	36	0.31	857	0.7	0.31
	Daphnia				16	0.03	0.64							8	0.01	0.54
	Chydorinae										92	0.15	0.44	66	0.1	0.4
	Cyclops	61	0.1	0.56	64	0.07	0.56	25,762	39	0.66	4,035	3.5	0.5	2,076	1.5	0.47
	Eurytemora	15,117	55	0.75	8	0.01	0.52	32,660	152	0.87						
	Harpacticoida	106	0.1	0.48	24	0.02	0.49	159	0.2	0.56	35	0.02	0.41	61	0.02	0.33
	Ergasilus	69	0.1	0.49										122	0.1	0.52
	Macrothricidae	106	0.04	0.33												
	TOTAL	**15,547**	**55.56**		**144**	**0.17**		**59,218**	**192.48**		**46,039**	**39.67**		**3,190**	**2.43**	
1995[2]	Bosmina				40	0.05	0.37	600	1.01	0.44	13,329	12	0.32			
	Chydorinae										272	0.32	0.36			
	Cyclops				40	0.03	0.46	2,471	2	0.49	2,158	1.5	0.49			
	Eurytemora	Not Sampled			56	0.31	0.98	25,481	64	0.6				Not Sampled		
	Harpacticoida										12	0.01	0.52			
	Scapholeberis										4	na[6]	0.48			
	TOTAL				**136**	**0.39**		**28,552**	**67.01**		**15,775**	**13.83**				
	Mean '93-'94				**152**	**0.24**		**40,305**	**142**		**52,061**	**50**		**2,890**	**2**	
	Mean '94-'95				**140**	**0.28**		**43,885**	**130**		**30,907**	**27**				
	Mean '93-'95				**147**	**0.29**		**36,387**	**117**		**39,966**	**38**				

- Continued -

Appendix B. (page 3 of 4)

NORTHCENTRAL

Year	Taxa	Ilnik			Wildman			Sandy			Bear			Sapsuk			Big Fish			S.W. Coast		
		D	B	S	D	B	S	D	B	S	D	B	S	D	B	S	D	B	S	D	B	S
1993[1]	Bosmina	64	0.06	0.32	171,047	208	0.37	3,530	3	0.34	101,645	167	0.42	147,293	312	0.48	186	0.15	0.34			
	Daphnia				427,679	1,252	0.81															
	Chydorinae	136	0.15	0.35	1,963,602	1,801	0.32	120	0.1	0.36												
	Cyclops	32	0.04	0.6	115,383	317	0.88	929	1	0.6	171,445	353	0.77	393,317	1,157	0.91	11,598	22	0.72	Not Sampled		
	Eurytemora							7,418	24	0.7							239	2.5	1.29			
	Harpacticoida	32	0.02	0.46	465	0	0.4															
	TOTAL	264	0.27		2,678,176	3,578		11,997	28.1		273,090	520		540,610	1,469		12,023	24.65				
1994[2]	Bosmina	382	0.5	0.35	386,479	442	0.36	1,747	1.7	0.33	404,694	931	0.49	164,992	314	0.46	144	0.4	0.53	64	0.09	0.39
	Daphnia	430	0.9	0.78	665,005	1,798	0.77	133	0.2	0.59										16	0.02	0.59
	Chydorinae	438	0.4	0.31	268,689	173	0.27	27	0.1	0.32							16	0.02	0.37			
	Cyclops	136	0.2	0.63	99,457	216	0.79	651	0.7	0.56	264,627	916	0.98	357,592	630	0.69	6,258	9	0.64	81,376	149	0.73
	Eurytemora	207	0.8	0.78				4,605	13	0.63							24	0.2	1.25	1,996	10	0.93
	Harpacticoida	8	0.01	0.44																		
	Ergasilus	8	0.01	0.6	443	0	0.48										8	0.01	0.52			
	Diaptomus																72	0.2	0.83			
	TOTAL	1,609	2.82		1,420,073	2,629		7,163	15.7		669,321	1,847		522,584	944		6,522	9.83		83,452	159.11	
1995[2]	Bosmina				319,002	336	0.35	2,420	2	0.34	275,256	615	0.48	116,271	215	0.46						
	Daphnia				46,373	143	0.82															
	Chydorinae				135,298	146	0.28															
	Cyclops				16,154	37	0.81	478	1	0.68	245,489	668	0.87	146,043	347	0.8						
	Eurytemora	Not Sampled						5,287	17	0.7							Not Sampled			Not Sampled		
	Harpacticoida				248	0.59	0.64															
	Ergasilus				301	0.5	0.58															
	TOTAL				517,376	663.09		8,185	20		520,745	1,283		262,314	562							
	Mean '93-'94	937	2					9,580	22		471,206	1,184		531,597	1,207		9,273	17				
	Mean '94-'95				968,725	1,646		7,674	18		595,033	1,565		392,449	753							
	Mean '93-'95				1,538,542	2,290		9,115	21		487,719	1,217		441,836	992							

- Continued -

Appendix B. (page 4 of 4)

UNALASKA ISLAND

Year	Taxa	Summer Bay			Unalaska			McLees			Lower Volcano			Upper Volcano		
		D	B	S	D	B	S	D	B	S	D	B	S	D	B	S
1993[1]	Bosmina	53	0	0				471,339	353	0	27,786	24	0			
	Daphnia							23,089	38	1	80	na[6]	na[6]			
	Chydorinae															
	Cyclops	207	0	0	Not Sampled			22,293	40	1	10,828	8	0	Not Sampled		
	Eurytemora	3,068	11	1												
	Harpacticoida															
	Ergasilus										557	1	1			
	Diaptomus															
	TOTAL	**3,328**	**11**					**516,721**	**431**		**39,251**	**33**				
1994[2]	Bosmina	282	0.31	0.35	143	0.1	0.33	136,970	121	0.31	7,282	5.8	0.31	43	0.12	0.55
	Daphnia				8	0.01	0.5	3,424	4	0.63				11	0.02	0.66
	Chydorinae	16	0.02	0.33	128	0.1	0.35				43	0.04	0.30	11	0.01	0.30
	Cyclops	1,651	1.30	0.50	80	0.1	0.55	24,708	26	0.56	7,244	6	0.50	414	0.51	0.60
	Eurytemora	25,473	93	0.75	1,083	3	0.64									
	Harpacticus				64	0.04	0.46							11	0.004	0.34
	Ergasilus										322	0.30	0.55			
	Diaptomus							531	1.4	0.84						
	TOTAL	**27,422**	**94.63**		**1,506**	**3.35**		**165,633**	**152.4**		**14,891**	**12**		**490**	**1**	
	Mean '93-'94	**15,375**	**53**					**341,177**	**292**		**27,071**	**23**				

1/ ~2 sample dates.
2/ ~4 sample dates.
3/ Marine taxa.
4/ Marine organisms present.
5/ No biomass estimates available for marine organisms.
6/ Data are not available (no measurements).

Appendix C. Alaska Peninsula fry sampling for diet analysis, 1994.

Lake	Date	Gear	No. Sets	Coho	Catch Sockeye	Other	Number Examined
Orzinski	6-11 Jun	?	?	?	?		25 sockeye
John Nelson	20 May	beach seine	6	50	50	0	30 sockeye
	17 Sep	beach seine	6	19	0	starry flounders	18 coho
Thin Point	24 May	beach seine	4		25		25 sockeye
	31 Aug	beach seine	6	70	0	starry flounders	24 coho
Morzhovoi	25 May	beach seine	2		25		25 sockeye
	30 Aug	beach seine	6	~45	~6	0 sticklebacks	16 coho
Sapsuk	28 May	beach seine	?	?	20		20 sockeye

Appendix D. Stomach content analysis of juvenile sockeye salmon collected from Orzinski, John Nelson, Thin Point, Morzhovoi, and Sapsuk Lakes, 1994.

Spring 1994

Classification	Taxa	Orzinski (6/6-11)		John Nelson (5/20)		Thin Point (5/24)		Morzhovoi (5/25)		Sapsuk (5/28)	
		%N	%F	%N	%F	%N	%F	%N	%F	%N	%F
	Empty	3.9	28	0.05	3.33	11.9	20			2.6	25
Sub-phylum	CRUSTACEA										
Class	COPEPODA										
Order	HARPACTICOIDA			6.2	20	21.4	16	20.9	72	20.8	30
Family	HARPACTICIDAE										
Genus	HARPACTICUS			2.3	53.3						
Genus	ZAUS			1	20						
Family	THALESTRIDAE										
Genus	DACTYLOPODIA			0.37	10						
Family	TISBIDAE										
Genus	TISBE			60.5	46.7						
Family	ECTINOSOMATIDAE			1.9	13.3						
Family	LAOPHONTIDAE			1.6	13.3						
	copepodids(immature)			1.7	6.7						
Order	CYCLOPOIDA			0.05	3.33	2.4	4	2	12	31.2	55
Family	ONCAEIDAE			6.2	10						
	nauplii									26.6	50
Order	CALANOIDA			0.1	6.7						
Family	EURYTEMORIDAE							60.4	32		
Class	BRANCHIOPODA										
Order	CLADOCERA										
Family	CHYDORIDAE					4.8	4	0.17	4		
Family	BOSMINIDAE										
Family	POLYPHEMIDAE									16.2	55
Genus	EVADNE			0..05	3.3						
Class	MALOCOSTRACA										
Order	AMHIPODA										
Sub-Order	GAMMARIDAE	11.1	28	2	43.3						
Family	COROPHIIDAE	13.9	4								
Order	CUMACEA			0.05	10						
Order	MYCIDACEA										
Family	MYSIDAE										
Genus	NEOMYSIS										
	neomysis mercedis					14.3	16	0.17	4		
Class	OSTRACODA			0.16	10						
Class	CIRRIPEDIA										
	nauplii			3.6	10						
	cyprid			0.11	6.8						
Sub-phyllum	CHELICERATA										
Class	ARACHNIDA					2.4	4	0.17	4		
Sub-phyllum	UNIRAMIA										
Class	INSECTA							7.5	28		
Order	COLLEMBOLA			6.6	36.8	14.3	16				
Order	DIPTERA					2.4	4	1.5	8		
	pupae			0.26	13.3	4.8	8	1.3	12	1.6	5
	larvae					14.3	16	3.3	52		
	parts										
Family	CHIRONOMIDAE							1.2	12		
Order	TRICHOPTERA							1.2	8		
	larvae										
Order	COLEOPTERA										
	pupae					2.4	4				
Phylum	NEMATODA	62.8	48	0.05	6.8	4.8	4	0.17	4		
Phylum	ROTIFERA			4.8	3.3					1	5
	Fish (salmonid)	7.8	16								
	Fish (unknown)	0.56	4								
Total Prey #:		180		1888		42		598		192	
Sample size:		25		30		25		25		20	
Fork Length (mm):		94		35.4		29.5		29.6		32.2	
Weight (g):		8.7		0.39		0.2		0.21		0.23	

-Continued-

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Fall 1994

Classification	Taxa	Thin Point (8/31)		Morzhovoi (8/30)		John Nelson (9/17)	
		%N	%F	%N	%F	%N	%F
	Empty					0.26	5.6
Sub-phylum	**CRUSTACEA**						
Class	**COPEPODA**						
Order	**HARPACTICOIDA**					20.4	11.1
Family	**HARPACTICIDAE**						
Genus	**HARPACTICUS**						
Genus	**ZAUS**						
Family	**THALESTRIDAE**						
Genus	**DACTYLOPODIA**						
Family	**TISBIDAE**						
Genus	**TISBE**						
Family	**ECTINOSOMATIDAE**						
Family	**LAOPHONTIDAE**						
	copepodids(immature)						
Order	**CYCLOPOIDA**						
Family	**ONCAEIDAE**						
	nauplii						
Order	**CALANOIDA**						
Family	**ACARTIIDAE**					7.4	5.6
Family	**EURYTEMORIDAE**						
Class	**BRANCHIOPODA**						
Order	**CLADOCERA**						
Family	**CHYDORIDAE**						
Family	**BOSMINIDAE**						
Family	**POLYPHEMIDAE**						
Genus	**EVADNE**					0.26	5.6
Genus	**PODON**					18.1	5.6
Class	**MALOCOSTRACA**						
Order	**AMHIPODA**					14.3	38.9
Sub-Order	**GAMMARIDAE**					27.3	61.1
Family	**COROPHIIDAE**						
Order	**CUMACEA**						
Order	**MYCIDACEA**						
Family	**MYSIDAE**						
Genus	**NEOMYSIS**						
	neomysis mercedis	38.3	70.8				
Class	**OSTRACODA**					0.5	5.6
Class	**CIRRIPEDIA**					2	5.6
	nauplii						
	cyprid						
Sub-phyllum	**CHELICERATA**						
Class	**ARACHNIDA**						
Order	**HYDRACARINA**			0.19	6.3		
Sub-phyllum	**UNIRAMIA**						
Class	**INSECTA**						
Order	**COLLEMBOLA**						
Order	**DIPTERA**						
	pupae						
	larvae			25.9	37.5		
	unknown					2	11.1
Family	**CHIRONOMIDAE**	0.27	8.3	64.3	100	1	22.2
Family	**PHORIDAE**			0.19	6.25		
Family	**SPHAEROCERIDAE**			0.19	6.25		
Family	**CULCIDAE**			0.38	12.5		

- Continued -

Appendix D. (page 3 of 3)

Fall 1994

Classification	Taxa	Thin Point (8/31)		Morzhovoi (8/30)		John Nelson (9/17)	
		%N	%F	%N	%F	%N	%F
Order	**DIPTERA** (continued)						
Family	**EPHYDRIDAE**			0.19	6.25		
Family	**COELOPIDAE**					0.26	5.6
Family	**BIBIONIDAE**					0.51	11.1
Family	**SCIARIDAE**					0.51	5.6
Family	**TABANIDAE**					0.26	5.6
Order	**TRICHOPTERA**			1.5	12.5	0.51	5.6
	larvae						
Order	**COLEOPTERA**	0.13	4.2				
	pupae						
Family	**STAPHYLINIDAE**			0.19	6.25		
Family	**DYSTICIDAE**			0.19	6.25		
	unknown			0.38	12.5		
Order	**HYMENOPTERA**	0.13	4.2				
	unknown			2.3	12.5	0.26	5.6
Family	**ICHNEUMONIDAE**			0.8	12.5	1.8	16.7
Family	**CHALCIDOIDAE**			0.19	6.3	0.26	5.6
Family	**BRACONIDAE**			0.38	12.5	0.26	5.6
Order	**HOMOPTERA**						
Family	**PSYLLIDAE**					0.26	5.6
Order	**PLECOPTERA**			0.38	6.3		
Phylum	**NEMATODA**	59.4	58.3				
Phylum	**ROTIFERA**						
Sub-Phylum	**VERTEBRATA**						
Class	**OSTEICHTHYES**						
Order	**CYPRINIFORMES**						
Family	**GASTRIMOYZONIDAE**	0.13	4.2				
Phylum	**ANNELIDA**						
Class	**HIRUDINAE**			1.5	37.5		
	Fish (salmonid)						
	Fish (unknown)	0.13	4.2				
	Salmonid eggs	1.3	8.3	0.95	6.25	1.5	11.1
	Unidentifiable	0.13	4.2				
Total Prey #:		747		529		392	
Sample size:		24		16		18	
Fork Length (mm):		97.1		65.4		66.5	
Weight (g):		11.9		4.1		3.9	

% N = % compostion (n/N%)

% F = % foreguts containing taxa (f/n%)

Appendix E. Orzinski, Sandy, Bear, and Sapsuk Lakes sockeye salmon smolt trapping catch by date, 1993 - 1995.

ORZINSKI LAKE SMOLT

Year	Date	Catch	Conditions[a]	Water Level (m)[a]
1994	7 Jun	7		
	8 Jun	2		
	9 Jun	1		
	11 Jun	11		
	12 Jun	15		
	18 Jun	6		
	19 Jun	3		
	20 Jun	4		
	21 Jun	255		
1995	12 Jun	48		
	16 Jun	30		
	28 Jun	95		
	29 Jun	27		
	30 Jun	0		

[a] No data available.

SANDY LAKE SMOLT

Year	Date	Catch	Conditions	Water Level (m)
1995	26 Jun	5	calm, 00	1.2
	27 Jun	13	calm	1.3
	1 Jul	~350	4000' overcast, scattered showers	1.4
	18 Jul	2	4000' overcast	1.3

BEAR LAKE SMOLT

Year	Date	Catch	Conditions	Water Level (m)
1993	31 May	20	sunny	
	2 Jun	~800	2000' overcast, calm, light rain	
	7 Jun	85	overcast, calm, light rain	2.68
	9 Jun	115	overcast, W 5-10	2.6
	15 Jun	140	overcast, fog, mist	2.42
	16 Jun	12	calm, rain	2.4
	17 Jun	~500	damp, fog, mist	
	18 Jun	~500	overcast, fog, mist, calm	2.4

BEAR LAKE SMOLT (contnued)

Year	Date	Catch	Conditions	Water Level (m)
1993	21 Jun	~1000	sunny, calm	2.38
	29 Jun	~500	3000' overcast, light rain	2.82
	6 Jul	~400	overcast, SE 10, water temp 7.4° C	2.88
	13 Jul	4	SE 25, water temp 10.1	2.75
	14 Jul	2	fog, mist, calm, water temp 8.6° C	2.8
	15 Jul	117	fog, mist, calm, water temp 9.1° C	2.8
	20 Jul	110	SE 20, rain	3.25
	1 Aug	2	fog, mist	
	2 Aug	16	CAVU, calm	
	3 Aug	70	clear, SE 25, water temp 10.7° C	2.78
1994	14 Jun	~850	100' overcast, vis 1-5	
	22 Jun	~450	4000' broken, vis 00	
	30 Jun	~700	High scattered, water high, turbid	
	6 Jul	~500		
	13 Jul	~450	200' overcast, vis 2	
	20 Jul	86	3000' overcast, vis 20+, SE 25-30	
	21 Jul	3	2000' broken, vis 20, SE 10	
	22 Jul	2	1000' overcast, fog, vis 5-10, SE 5	
1995	15 Jun	2000+		
	23 Jun	1	fog, calm	
	24 Jun	~500	Broken	
	29 Jun	165	2000' overcast, vis 5-10	
	30 Jun	~275		
	8 Jul	85	fog, calm	
	9 Jul	4	E 15-20, light rain, vis 10	
	11 Jul	73	3000' scattered, W 10-15, vis 20	
	16 Jul	230	500' overcast, fog, vis 8-10	
	23 Jul	75	rain, fog, W 15-20	
	24 Jul	6		

SAPSUK LAKE SMOLT

Year	Date	Catch	Conditions[a]	Water Level (m)[a]
1995	25 May	75		

[a] No data available.

Appendix F. Measurements of total habitat, the amount of usable habitat, and sockeye spawning capacity for Bear Lake tributaries and outlet stream.

Clear Creek

Stream Block	Habitat (m^2)	Usable Habitat (%)	Usable Habitat (m^2)	Spawning Capacity
1	2,865	20	573	573
2	3,200	20	640	640
3	2,316	5	116	116
4	2,195	45	988	988
5	2,469	10	247	247
6	1,951	30	585	585
7	1,463	90	1,317	1,317
8	2,164	40	866	866
9	2,469	1	25	25
10	2,347	50	1,173	1,173
11	2,134	50	1,067	1,067
12	2,256	80	1,804	1,804
13	2,408	60	1,445	1,445
14	2,103	70	1,472	1,472
15	2,103	90	1,893	1,893
16	2,316	95	2,201	2,201
17	2,316	100	2,316	2,316
18	2,957	95	2,809	2,809
19	2,957	75	2,217	2,217
20	1,829	20	366	366
21	1,707	80	1,366	1,366
22	2,560	80	2,048	2,048
23	2,835	60	1,701	1,701
24	2,103	70	1,472	1,472
25	1,494	90	1,344	1,344
26	1,158	60	695	695
27	1,280	65	832	832
28	1,707	80	1,366	1,366
29	2,225	90	2,003	2,003
30	2,164	90	1,948	1,948
31	2,164	65	1,407	1,407
32	2,195	80	1,756	1,756
33	1,676	65	1,090	1,090
34	1,829	55	1,006	1,006
35	1,829	95	1,737	1,737
36	1,890	95	1,795	1,795
37	2,073	90	1,865	1,865
38	1,710	75	1,282	1,282
39	1,250	90	1,125	1,125
40	1,372	90	1,234	1,234
41	1,768	80	1,414	1,414

-Continued-

Clear Creek (continued)

Stream Block	Habitat (m^2)	Usable Habitat (%)	Usable Habitat (m^2)	Spawning Capacity
42	2,012	90	1,811	1,811
43	1,463	100	1,463	1,463
44	1,189	90	1,070	1,070
45	1,311	100	1,311	1,311
46	1,372	90	1,234	1,234
47	1,707	100	1,707	1,707
48	2,042	80	1,634	1,634
49	1,798	100	1,798	1,798
50	1,128	90	1,015	1,015
51	1,189	65	773	773
52	1,554	90	1,399	1,399
53	2,621	100	2,621	2,621
54	1,707	70	1,195	1,195
55	1,554	85	1,321	1,321
56	1,890	95	1,795	1,795
57	1,646	70	1,152	1,152
58	1,554	80	1,244	1,244
59	1,646	65	1,070	1,070
60	1,524	65	991	991
61	1,372	95	1,303	1,303
Total			**82,510**	**82,510**

Cub Creek

Stream Block	Habitat (m^2)	Usable Habitat (%)	Usable Habitat (m^2)	Spawning Capacity
1	2,652	100	2,652	2,652
2	2,652	100	2,652	2,652
3	2,591	80	2,073	2,073
4	2,896	35	1,013	1,013
5	2,896	30	869	869
6	2,316	35	811	811
7	2,042	35	715	715
8	1,859	30	558	558
9	1,707	10	171	171
10	2,164	40	866	866
11	2,499	15	375	375
12	1,707	15	256	256
13	1,158	5	58	58
Total			**13,067**	**13,067**

-Continued-

Red Creek

Stream Block	Habitat (m^2)	Usable Habitat (%)	Usable Habitat (m^2)	Spawning Capacity
1	2,621	100	2,621	2,621
2	2,469	100	2,469	2,469
3	1,524	100	1,524	1,524
4	1,311	100	1,311	1,311
Total			**7,925**	**7,925**

Bear Lake Outlet

Stream Block	Habitat (m^2)	Usable Habitat (%)	Usable Habitat (m^2)	Spawning Capacity
1	39,020	50	19,510	19,510

Bear Lake Shoreline Spawning Habitat Calculation

Surface	10 Meters	(Total/2) x 100	Total/3.1[a]
2.23	1.58	190.5	61.5
1.43	1.09	126.0	40.6
2.04	1.65	184.5	59.5
1.62	0.95	128.5	41.5
0.05	0.12	8.5	2.7
0.80	0.24	52.0	16.8
0.94	0.94	94.0	30.3
2.08	0.36	122.0	39.4
2.28	2.00	214.0	69.0
0.07	0.07	7.0	2.3
13.54	9.00	1,127.0	**363.5 km^2**

[a] Spawning area was estimated to a depth of 3.1 meters.

System Totals

	Usable Habitat (m^2)	Spawning Capacity
Clear Creek Total:	**82,510**	**82,510**
Cub Creek Total:	**13,067**	**13,067**
Red Creek Total:	**7,925**	**7,925**
Lake Outlet Total:	**19,510**	**19,510**
Lake Shore Total:	**363,550**	**363,550**
Bear Lake Creeks and Outlet Total:	**486,562**	**486,562**

Appendix G. Measurements of total habitat, the amount of usable habitat, and sockeye spawning capacity for Sapsuk Lake tributaries.

Voodoo Creek

Stream Block	Habitat (m^2)	Usable Habitat (%)	Usable Habitat (m^2)	Spawning Capacity
1	1,426	60	856	856
2	1,100	60	660	660
3	1,200	60	720	720
4	1,087	60	652	652
5	1,872	70	1,311	1,311
6	1,219	60	731	731
7	743	100	743	743
8	768	100	768	768
9	1,129	80	903	903
10	172	15	26	26
LT. FORK				
11	823	90	741	741
12	101	90	91	91
13	832	40	333	333
TOTALS			**8,534**	**8,534**

Happy Valley Creek

Stream Block	Habitat (m^2)	Usable Habitat (%)	Usable Habitat (m^2)	Spawning Capacity
1	1,219	30	366	366
2	1,056	60	634	634
3	1,268	100	1,268	1,268
4	1,100	90	990	990
5	1,248	80	999	999
6	921	80	737	737
7	1,486	80	1,189	1,189
8	1,456	80	1,165	1,165
9	1,100	100	1,100	1,100
10	1,250	40	500	500
11	1,792	100	1,792	1,792
12	1,248	100	1,248	1,248
TOTALS			**11,987**	**11,987**

-Continued-

RED BONE CREEK

Stream Block	Habitat (m^2)	Usable Habitat (%)	Usable Habitat (m^2)	Spawning Capacity
1	713	100	713	713
2	951	95	903	903
3	1,010	65	657	657
4	832	65	541	541
5	773	80	618	618
6	1,129	90	1,016	1,016
7	1,295	50	648	648
8	1,070	65	695	695
9	572	100	572	572
10	666	80	533	533
11	862	70	603	603
12	796	85	676	676
13	1,043	95	991	991
14	1,129	60	678	678
15	674	50	337	337
16	1,097	80	878	878
TOTALS			**11,059**	**11,059**

Sapsuk Lake Shoreline Spawning Habitat Calculation

Surface	10 Meters	(Total/2) x 100	Total/3.1[a]
6.13	5.59	586.0	189.0
0.09	0.05	7.0	2.3
0.07	0.05	6.0	1.9
1.25	1.32	128.5	41.5
0.36	0.39	37.5	12.1
7.90	7.40	765.0	**246.8 km^2**

[a] Spawning area was estimated to a depth of 3.1 meters.

System Totals

	Usable Habitat (m^2)	Spawning Capacity
Voodoo Creek Total:	**8,534**	**8,534**
Happy Valley Creek Total:	**11,987**	**11,987**
Red Bone Creek Total:	**11,059**	**11,059**
Supper Creek Total:[a]	**10,000**	**10,000**
Lake Shore Total:	**246,800**	**246,800**
Sapsuk Lake Creeks Total:	**288,380**	**288,380**

[a] Foot survey estimate, 10 August 1993.

Appendix H. Pathology reports on the results of sockeye and coho salmon disease screening. (p 1 of 9)

ACCESSION NO: 94-0027

ALASKA DEPARTMENT OF FISH AND GAME
FISH PATHOLOGY SECTION, CFM&D DIVISION
333 RASPBERRY ROAD, ANCHORAGE, AK 99518-1599

REPORT OF LABORATORY EXAMINATION

LOT (YEAR, STOCK, SPECIES): Orzinski Lake sockeye salmon, Oncorhynchus nerka

FACILITY: ADF&G/CFM&D

CONTACT PERSON/ADDRESS: Steve Honnold, 211 Mission Road
Kodiak, AK 99615-6399

SAMPLE DATE: 08/09/93 *DATE SAMPLE RECEIVED:* 08/12/93

SPECIMEN TYPE: kidneys & ovarian fluids *LIFE STAGE:* adult *STATE:* fresh

NUMBER IN SAMPLE: 62 kidneys
65 ovarian fluids *WILD:* yes

HISTORY/SIGNS:

REASON FOR SUBMISSION: Broodstock screening.

FINAL REPORT DATE: 11/23/93

CLINICAL FINDINGS:

FAT: 0/62 positive for *Aeromonas salmonicida*
0/62 positive for *Yersinia ruckeri* Type I
0/62 positive for *Yersinia ruckeri* Type II

ELISA: 0/62 positive for *Renibacterium salmoninarum* (Rs). Mean optical density values $\geq$ 0.095 were considered positive for the Rs antigen.

VIROLOGY: 0/64 positive for IHNV. Plaque assay on EPC cell line at 15°C for 7 days. Minimum level of detection = 10 PFU/ml.

One sample had previously been thrown out because the contents had leaked from the tubes.

DIAGNOSIS: The agents for IHN disease, BKD, furunculosis and enteric redmouth were not found.

COMMENTS/RECOMMENDATIONS: No Rs antigen was detected in the kidney samples submitted. Based on the samples submitted, the stock would be suitable for broodstock use.

FISH HEALTH INVESTIGATOR: Roger R. Saft, Ted Meyers

TECHNICAL ASSISTANCE: Tammy Burton, Jana Geesin, Karen Lipson, Sally Short, Norman Starkey

COPIES TO: FY94, Misc., Burkett, Meyers, White

Accession No: 94-0027

ACCESSION NO: 94-0031

ALASKA DEPARTMENT OF FISH AND GAME
FISH PATHOLOGY SECTION, CFM&D DIVISION
333 RASPBERRY ROAD, ANCHORAGE, AK 99518-1599

REPORT OF LABORATORY EXAMINATION

LOT (YEAR, STOCK, SPECIES): Sapsuk Lake sockeye salmon, Oncorhynchus nerka

FACILITY: ADF&G/CFM&D Division

CONTACT PERSON/ADDRESS: Steve Honnold, 211 Mission Road Kodiak, AK 99615-6399

SAMPLE DATE: 08/16/93 DATE SAMPLE RECEIVED: 08/18/93

SPECIMEN TYPE: kidneys & ovarian fluids LIFE STAGE: adult STATE: fresh

NUMBER IN SAMPLE: 60 kidneys WILD: yes
60 ovarian fluids

HISTORY/SIGNS: NA

REASON FOR SUBMISSION: Broodstock screening.

FINAL REPORT DATE: 12/09/93 - Report amended on 12/29/93

CLINICAL FINDINGS:

FAT: 0/60 positive for Aeromonas salmonicida
0/60 positive for Yersinia ruckeri Type I
0/60 positive for Yersinia ruckeri Type II

ELISA: 8/60 (13.3%) positive for Renibacterium salmoninarum (Rs). Mean optical density values $\geq$ 0.095 were considered positive for the Rs antigen.

Positive values ranged from 0.098 to 0.115 with an average of 0.105.

VIROLOGY: 39/60 positive for IHNV (65%). Plaque assay on EPC cell line at 15°C for 7 days. Minimum level of detection = 10 pfu/ml.

Titer Distribution

Titer	neg	10^1	10^2	10^3	10^4	10^5	10^6	10^7
# of fish	21	19	9	2	5	3	0	1
% of total	35%	32%	15%	3%	8%	5%	0%	2%

Percent positives with titers $\geq 10^4$ = 9/39 = 24%

DIAGNOSIS: The soluble antigen for BKD was detected. The IHN virus was also found.

COMMENTS/RECOMMENDATIONS: A low prevalence of low level Rs antigen was detected in the kidney samples submitted. The agents for furunculosis and Enteric Redmouth were not detected. Moderate numbers of low IHN virus titer fish were present.

FISH HEALTH INVESTIGATOR: Roger R. Saft, Ted Meyers

TECHNICAL ASSISTANCE: Tammy Burton, Jana Geesin, Karen Lipson, Sally Short, Norman Starkey

COPIES TO: FY94, Misc., Burkett, Meyers

Accession No: 94-0031

ALASKA DEPARTMENT OF FISH AND GAME
FISH PATHOLOGY SECTION, F.R.E.D. DIVISION
333 RASPBERRY ROAD, ANCHORAGE, AK 99518-1599
PHONE 267-2244

REPORT OF LABORATORY EXAMINATION

SAMPLE DATE: 9/17/87 LOG NO: 880055 DATE SAMPLE RECEIVED: 9/18/87
FACILITY: Russell Creek hatchery CONTACT PERSON: Clayton Brown
SPECIMEN TYPE: ovarian fld.,kid. NUMBER IN SAMPLE: 63,64
BROOD YEAR: wild BROOD SOURCE: Mortensen L
SPECIES: sockeye STAGE: adult STATE: ovar. fld.frozen -80C
HISTORY/SIGNS: N/A (postspawning) kid. on ice

REASON FOR SUBMISSION: IHNV, BKD, Furunculosis Broodstock Screening
FINAL REPORT DATE: February 23, 1988

CLINICAL FINDINGS

VIROLOGY: 24/ 63 POSITIVE FOR IHNV (38.1 %)
HIGH TITER > or = 1.0E04) SAMPLES: 2/ 24 (8.3%)
A plaque assay using EPC cells was conducted at 15C with a minimum level of detection of 10 PFU/ml.
GEOMETRIC MEAN TITER: 8.3E+02 (SD 1.7E+01)
ARITHMETIC MEAN TITER: 2.5E+05 (SD 1.1E+06)
MEAN PERCENT INCIDENCE OF DATA BASE: 39.0
GEOMETRIC MEAN TITER OF DATA BASE: 4.9E+05

FAT: 0/64 POSITIVE FOR RENIBACTERIUM SALMONINARUM
0/64 POSITIVE FOR AEROMONAS SALMONICIDA

DIAGNOSIS: IHNV prevalence slightly below mean, titers far below mean
The agents for BKD and furunculosis were not detected in this stock.

TREATMENT: N/A

RECOMMENDATION: suitable for broodstock use

FISH HEALTH INVESTIGATOR: R. Saft, J. Sullivan

COPIES TO: 6.8.8, 6.4.10, Meyers, Burkett, McDaniel

ALASKA DEPARTMENT OF FISH AND GAME
FISH PATHOLOGY SECTION, F.R.E.D. DIVISION
333 RASPBERRY ROAD, ANCHORAGE, AK 99518-1599
PHONE 267-2244

REPORT OF LABORATORY EXAMINATION

SAMPLE DATE: 9/16/88 ACCESSION NO: 89-0046 DATE SAMPLE RECEIVED: 9/19/88

CONTACT PERSON/FACILITY: Clayton Brown, Russell Creek Hatchery, ADF&G

LOT (YEAR, STOCK, SPECIES): Mortensen Creek sockeye

STAGE: Adult (ripe) WILD: Yes

NUMBER IN SAMPLE: 62 SPECIMEN TYPE: Ovarian fluids

STATE: Received on ice, then frozen at -80°C

HISTORY/SIGNS: N/A

REASON FOR SUBMISSION: Broodstock screening for IHNV

FINAL REPORT DATE: 11/7/88

CLINICAL FINDINGS:

VIROLOGY: 3/60 (5%) positive for IHNV, 2 samples rejected due to toxicity
Plaque assay on EPC cell line at 15°C for 7 days
Minimum level of detection = 10 PFU/ml

Titer distribution

	neg*	10^1	10^2	10^3	10^4	10^5	% of positives with titers $\geq 10^4$ PFU/ml
# of fish	57	0	1	0	1	1	67%
% of total	95	0	1.7	0	1.7	1.7	

* <10 PFU/ml

COMMENTS: The prevalence of IHNV was fairly low (5%) this year compared to 38% (88-0055) last year. Maintain strict isolation and disinfection procedures and notify Fish Pathology Lab of any significant mortalities.

FISH HEALTH INVESTIGATOR: J. Thomas JThomas

COPIES TO: 6.8.9, 6.4.10, T. Meyers, R. Burkett, T. McDaniel

TOM

ALASKA DEPARTMENT of FISH and GAME **** F.R.E.D. DIVISION
FISH DISEASE HISTORIES

AccessNo		SAMPLE DATE	BROOD YEAR	BROOD SOURCE	SPECIES	AGE	HATCHERY/ REQUESTOR	FINDINGS and COMMENTS:
950028	SC	09/03/94	WILD	RUSSELL CR	COHO	ADULT	ADFG KODIAK	0/57 BKD ELI (0%) 2/57 Y.RUCK (3.5%) 0/57 A.SAL (0%) OTHER: 2/57 ERM II not confirmed;0/57 ERM I. RECOMMEND: Suitable for broodstock.

ACCESSION NO: 94-0039

ALASKA DEPARTMENT OF FISH AND GAME
FISH PATHOLOGY SECTION, CFM&D DIVISION
333 RASPBERRY ROAD, ANCHORAGE, AK 99518-1599

REPORT OF LABORATORY EXAMINATION

LOT (YEAR, STOCK, SPECIES): John Nelson Lake coho salmon, *Oncorhynchus kisutch*

FACILITY: ADF&G/CFM&D

CONTACT PERSON/ADDRESS: Lorne White 211 Mission Road
Kodiak, AK 99615

SAMPLE DATE: 09/12/93 DATE SAMPLE RECEIVED: 09/14/93

SPECIMEN TYPE: kidneys LIFE STAGE: adult STATE: frozen

NUMBER IN SAMPLE: 63 kidneys WILD: yes

HISTORY/SIGNS: NA

REASON FOR SUBMISSION: Broodstock screening.

FINAL REPORT DATE: 10/25/93

CLINICAL FINDINGS:

FAT: 0/63 positive for *Aeromonas salmonicida*
0/63 positive for *Yersinia ruckeri* Type I
1/63 positive for *Yersinia ruckeri* Type II, not confirmed in culture.

ELISA: 0/63 positive for *Renibacterium salmoninarum* (Rs). Average optical density values $\geq$ 0.095 were considered positive for the Rs antigen.

COMMENTS/RECOMMENDATIONS: No Rs antigen was detected in the kidney tissues submitted. The finding of *Y. ruckeri* was not confirmed in culture but eggs taken should be disinfected as per standard procedures. If this stock is to be used for broodstock, please submit 60 ovarian fluid samples to complete the disease history.

FISH HEALTH INVESTIGATOR: Tammy Burton, Jill Follett, Jana Geesin, Ted Meyers

TECHNICAL ASSISTANCE: Karen Lipson, Sally Short, Norman Starkey

COPIES TO: FY94, Misc., Burkett, Meyers

ALASKA DEPARTMENT OF FISH AND GAME
FISH PATHOLOGY SECTION, F.R.E.D. DIVISION
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REPORT OF LABORATORY EXAMINATION

SAMPLE DATE: 11/4/87 ACCESSION NO: 88-0099 DATE SAMPLE RECEIVED: 11/9/87

CONTACT PERSON/FACILITY: Clayton Brown, Russell Creek Hatchery

SPECIMEN TYPE: Kidneys STATE: On ice STAGE: Adults

NUMBER IN SAMPLE: 60 WILD: Yes

LOT (YEAR, STOCK, SPECIES): Mortensen Creek coho

HISTORY/SIGNS: N/A

REASON FOR SUBMISSION: Broodstock evaluation

FINAL REPORT DATE: 11/30/87

CLINICAL FINDINGS:

FAT: 0/60 positive for Aeromonas salmonicida and Renibacterium salmoninarum.

COMMENT & RECOMMENDATION: No BKD or furunculosis causing organisms were detected. With regard to these two diseases, this stock may be used as a broodstock.

FISH HEALTH INVESTIGATOR: K. Saft

COPIES TO: 6.8.8, 6.4.10, Meyers, Burkett, McDaniel

Appendix I. Peak escapement counts and estimated total escapement of coho salmon by system for the Alaska Peninsula, 1990.

System	Coho Escapement Peak	Total
Orzinski	1,200	2,880
Russell Creek	2,200	5,280
Mortensen	3,000	7,200
Thin Point	4,200	10,080
Meshik/Port Heiden	19,000	45,600
Mud Creek	4,000	9,600
Cinder River	3,000	7,200
Ilnik	24,000	57,600
Nelson River	30,000	72,000
Swanson's Lagoon	4,500	10,800

Source: Murphy and Roche, Alaska Peninsula and Aleutian Islands Management Areas Salmon Catch, Escapement, and Run Statistics, 1990.

Appendix J. Projected annual cost to stock sockeye fry, pre-smolt, smolt, and conduct lake fertilization; includes estimated production and benefits.

	20 million fry	1 million pre-smolt	1 million smolt	Fertilization/Lake
Eggtake[a]	$40,000	$30,000	$25,000	
Incubation[a]	$40,000	$60,000	$80,000	
Rearing[a]	$50,000	$100,000	$200,000	
Transport[a]	$40,000	$60,000	$80,000	
Operations/Maintenance[a]	$150,000	$150,000	$150,000	
Fertilizer application[b]				$50,000
Evaluation[b]	$300,000	$300,000	$300,000	$150,000
Total Cost *	$620,000	$700,000	$835,000	$200,000
Survival assumption[c]	1.5%	10%	15%	
Potential Production[c]	400,000	125,000	200,000	
Potential Benefit[d]	$2,000,000	$625,000	$1,000,000	

* Does not include reconfiguration of Russell Creek Hatchery which could exceed $ 2 million; this includes thermal marking design (B. McCurtain, ADF&G, personal communication, Anchorage).

Sources: [a] C. Clevenger, ADF&G, personal communication, Kodiak.

[b] L. Malloy, KRAA, personal communication, Kodiak.

[c] Honnold and Clevenger, 1995.

[d] based on $5.00/sockeye